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Descriptive Data Analytics for the Stimulation, Completion Activities, and Wells' Productivity in the Marcellus Shale Play

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Abstract

Drilling, completion, and stimulation designs have changed over time as a result of the oil and gas industry's ongoing efforts to increase well productivity. Over the last five years hydraulic fracturing treatments, represented by the volume of pumped water and the amount of proppant utilized, have increased significantly, along with the lengths of horizontal wells. This work represents a large-scale descriptive analysis study to illustrate the trends and the range of completion, stimulation and production parameters in the Marcellus Shale play of the Appalachian Basin between 2012 and the last quarter of 2017 (2012-2018).

A database was created by combing stimulation fluids and proppant data from the FracFocus 3.0 chemical registry, with completion and production data from the DrillingInfo database. More than 2000 Marcellus Shale wells were utilized in this study. The data were processed and cleaned from outliers. Box plots and distribution bar charts are presented for most of the parameters in this study, to show the range in values for each parameter and its frequency of use. The stimulation parameters were normalized to perforated lateral length in order to compare productivity between the wells.

Trends identified in this study show how operators in the Marcellus have increased the use of hybrid fracturing fluids, in addition to increasing water and proppant volumes over time. The work also illustrates the point at which increasing fracture treatment volumes no longer increases production rate.

This paper demonstrates the utility of integrating publicly available databases to examine well completion trends in the Marcellus. The work also provides a summary of well response as a function of treatment volume over the five year study period.

Introduction

Over the last decade, the United States experienced tremendous growth in unconventional oil and gas resource development, primarily in the shale plays. This growth is mainly attributed to the success in coupling horizontal drilling with multi-stage hydraulic fracturing to produce oil and gas from ultra-low permeability, or 'tight' resources. Energy information administration (EIA) (2018) reports over 120,000 active horizontal wells completed since the year 2000. A large amount of data from drilling, completion, stimulation, and production of these wells is available, often in different databases. Analysis of such data can provide insights into completion trends and their impact on well productivity, methods of gaining operational efficiency, cost saving, as well as health, safety and environmental considerations.

Shale development history, trends, and best practices have been documented by many studies in the literature. Some earlier studies lacked formation descriptive data which made it difficult to utilize the findings and generalize it to the field level because the data were limited to small number of localized wells representing a small, area specific trend (Carman et al, 2018). However, with data being shared more readily and more accessible databases available, more recent studies have provided reviews of shale development trends (Yang et al., 2013; Arthur et al., 2014; Romero and Poston, 2016; Luo and Zhang, 2018; Olaoye and Zakhour, 2018; Srinivasan et al., 2018; Carman and Wheeler, 2018; Weijers et al., 2019). Myers et al. (2017) provides a production analysis summary of the Marcellus Shale. Other recent case studies of various shale development trends provide useful insight to maximize well productivity (Al-Alwani et al., 2019a; Al-Alwani et al., 2019b; Al-Alwani et al., 2019c; Al-Alwani et al., 2019d; Al-Alwani et al., 2019e).

As with many other industries, the oil and gas industry has begun utilizing descriptive and predictive data analytics in processes optimization, future planning, and to help in making data-based decisions. The use of data analytics in the oil and gas industry has been described by Khvostichenko and Makarychev-Mikhailov (2018) as the most dynamically growing fields. Many of the leading operators and service companies have realized the power of data-driven decisions and have developed specialized teams to review their accumulated data and analyze trends, in an effort to improve performance. Although large scale data analytics are relatively new to the oil and gas industry, this field has been advanced by many of the studies noted previously. Mohaghegh et al. (2017) demonstrates optimizing Marcellus well production through data analysis using artificial intelligence (AI) methods. Shahkarami et al. (2018) presents a Marcellus data analysis using machine learning algorithms. Data science and machine learning approaches are also used extensively by the Department of Energy oil and gas research to process the complex data streams generated by drilling, stimulation, and production to increase the productivity of the oil and gas wells (Oil & Gas Journal, 2019).

In this study, data were collected from FracFocus 3.0 (2019), the publically available chemical registry containing chemical and proppant data for stimulated wells. These data were combined with drilling, completion and production data available through DrillingInfo (2019) and processed to create a final database that integrates stimulation and completion parameters with production data. This database was analyzed to identify trends of completion and stimulation over a five year period (2012-2017) and to quantify the stimulation and completion parameters effects on the wells' productivity. Proppant loads, water volumes, lateral length increases, types of stimulation fluids used, the response of combined stimulation and completion parameters on production, and other normalized parameters are all discussed in this work.

Marcellus Shale and Its Contribution to Energy Supply

The Marcellus Shale is a gas play located in the Appalachian Basin. It consists mainly of black shale interbedded by some layers of limestone. The formation was known to contain hydrocarbons for many years but was uneconomic to produce with vertical well completions. In 2003, Range Resources drilled a well using horizontal well technology combined with multistage hydraulic fracturing that had been found to be efficient in the Barnett Shale in Texas (Harper, 2008). This well proved successful and, as of November, 2017, EIA reported more than 11,300 wells have now been drilled in the Marcellus Shale as shown in Figure 1 (EIA, 2017).

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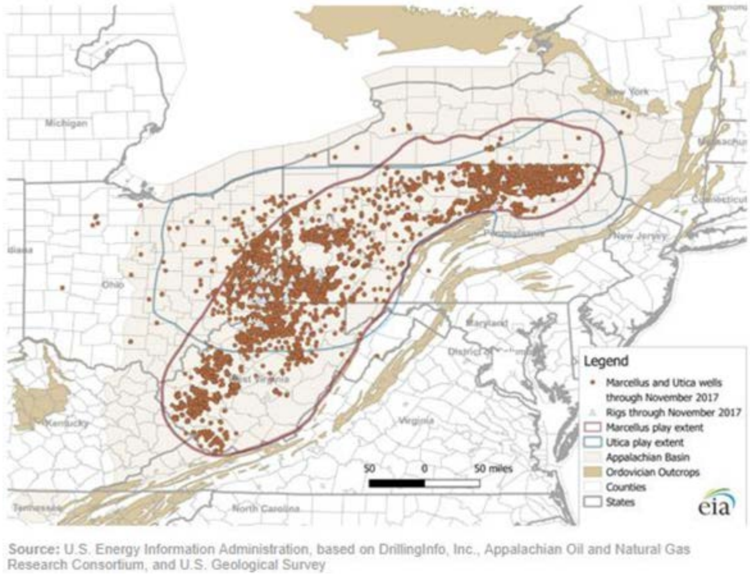

Figure 1—Marcellus producing wells as of November 2017 (EIA, 2017)

The Marcellus Shale is now one of the largest shale plays in the U.S. and contributes significantly to U.S. gas production. Over the past decade, the Appalachian Basin has contributed 85% of all the growth in U.S. gas production, and is now equal to approximately one-third of current U.S. gas production. Predictions suggest that Marcellus gas production will account for about 45% of the U.S. entire gas production by 2040 (Oil & Gas Journal, 2019).

Data and Methods

Data for this study were collected from FracFocus as well as DrillingInfo. A comprehensive database was built by extracting the chemical ingredients data for every Marcellus well stimulated and reported in FracFocus. Chemcial volumes, trades names, and use were obtained, along with all chemical mass percentages. FracFocus data were processed then combined with completion and production data for the Marcellus Shale wells obtained from DrillingInfo. The data from FracFocus are available to the public but require rigorous cleaning and processing for use.

The main objective in processing the data from FracFocus was to identify and categorize the stimulation fluid types based on the individual chemical ingredients that are reported in the list of treatment ingredients.

After extracting the data from FracFocus a series of data processing and formatting was applied to combine all the data in one file to be ready for the next phase of data analysis. Chemical ingredients were reported by several identifiers such as the chemical ingredient name, commercial name, and the chemical abstract service number (CAS#). There is inconsistency in the way fracturing fluids and their ingredients are named and reported in FracFocus, making it difficult to use chemical names in the analysis. Many operators simply report the names based on their own standards. In addition, there are many chemical naming abbreviations and typos. For this study and for the purpose of classifying the chemical ingredients into several groups (e.g. gelling agents, cross-linkers, surfactants), the CAS# was chosen to be the main identifier for each chemical ingredient. A data analysis technique, referred to as TreeMap charts, was applied to sort the chemical data into 19 prospective groupings based on their CAS# and the number of wells sharing the same chemical ingredient. Environmental protection agency (EPA) safer chemical ingredients list and a study conducted by Helmholtz Zentrum München, Institute of groundwater ecology (which provides a complete list of all hydraulic fracturing chemicals extracted from the Waxman list and the FracFocus database) were utilized in identifying the prospective chemical groups (Elsner & Hoelzer, 2016; EPA, 2019).

After the 19 chemical groups were generated, the groups were individually processed to eliminate any potential duplication in the reporting process from FracFocus. Once duplication issues were resolved, re- fractured wells were identified in the data processing workflow and grouped separately to eliminate aggregating several frac-jobs' ingredients into one well rather than separately assigning the appropriate number of fracturing jobs per well. Once all the ingredients mass percentage for the specific chemical group were summed up and assigned for each well, the following step was to combine all the chemical groups together into one dataset representing the processed FracFocus. Following that, multiple new parameters were calculated based on the processed data such as the calculated total proppant mass and the ingredients' concentrations. Figure 2 shows a workflow that combines all the processed chemical groups obtained from FracFocus. The final database was created by matching the production and completion data from DrillingInfo with the chemical components for each well. This combined database was quality checked. Several normalized parameters were also introduced to the database to help in the analysis phase and to generate production, completion, and stimulation insights for the Marcellus Shale stimulated wells. Al-Alwani et al. (2019c) presents a more detailed discussion of the procedures used to create the final database.

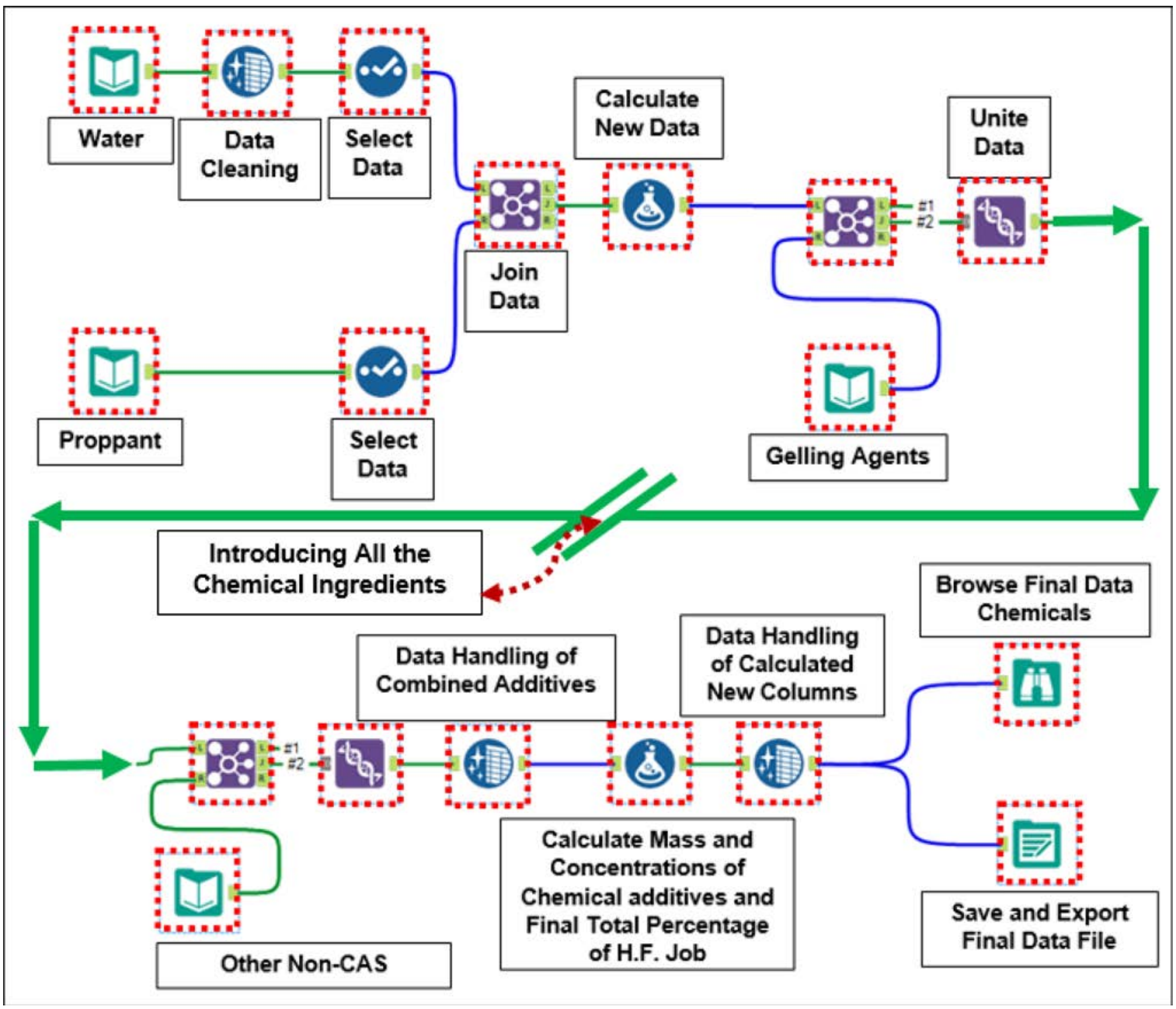

Figure 2—Data Processing Workflow to Combine All of the FracFocus Processed Data into One Database File

More than 2000 Marcellus wells were identified with sufficient data for trend analysis and to provide insights regarding completions in the Marcellus Shale. The wells, and their type of stimulation fluid used, are distributed widely across Pennsylvania and West Virginia as illustrated in Figure 3.Figure 4 shows the number of wells per each stimulation fluid type between 2012 and 2018. Water stimulation fluid treatments dominate all other fluid treatment over the entire period. Beginning in 2015, hybrid fluid treatments increase and in 2017 are only slightly less than water treatments. Both linear gel and cross linked gel treatments have grown in use in 2017, which may be attributed to longer lateral lengths.

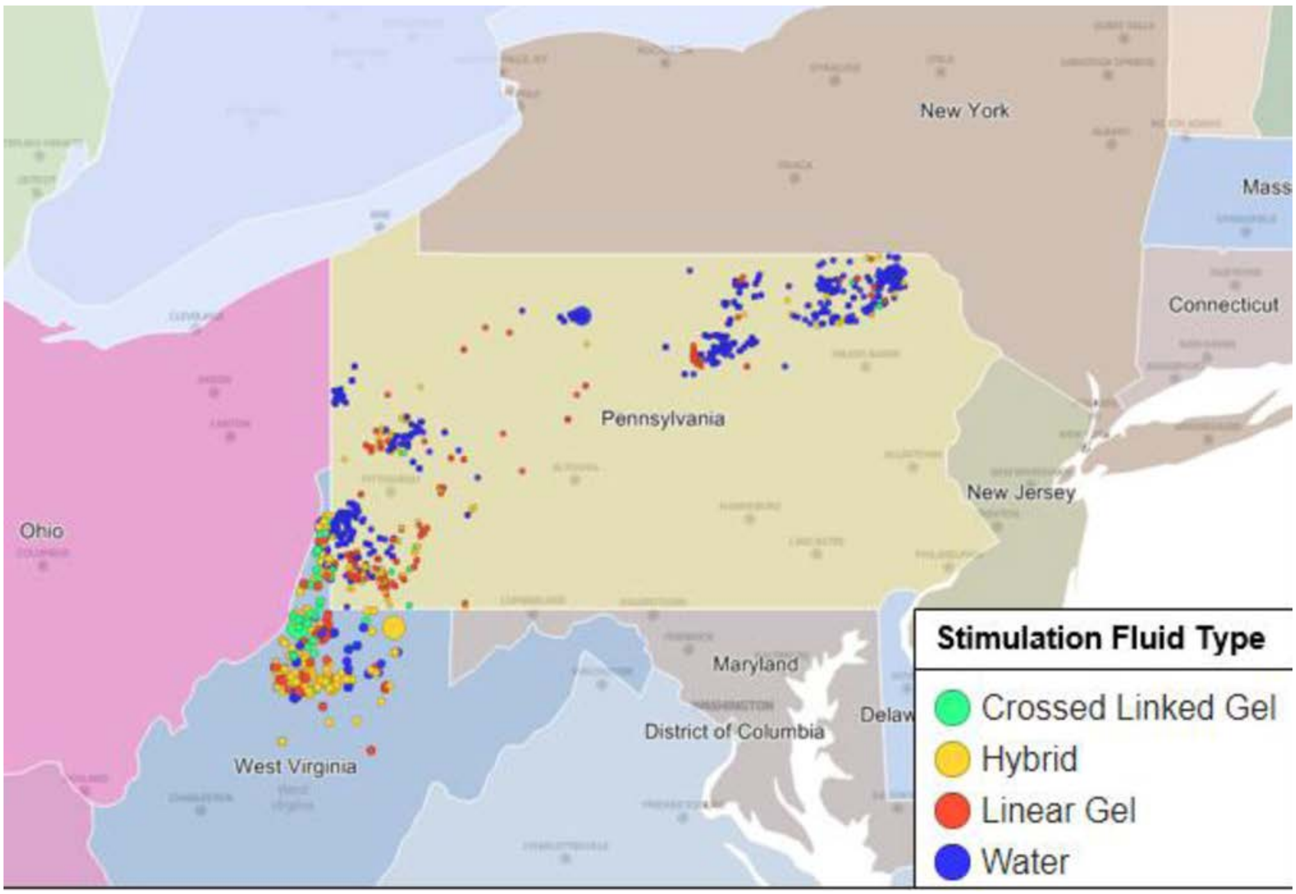

Figure 3—Appalachian Basin Wells Distribution on the Map

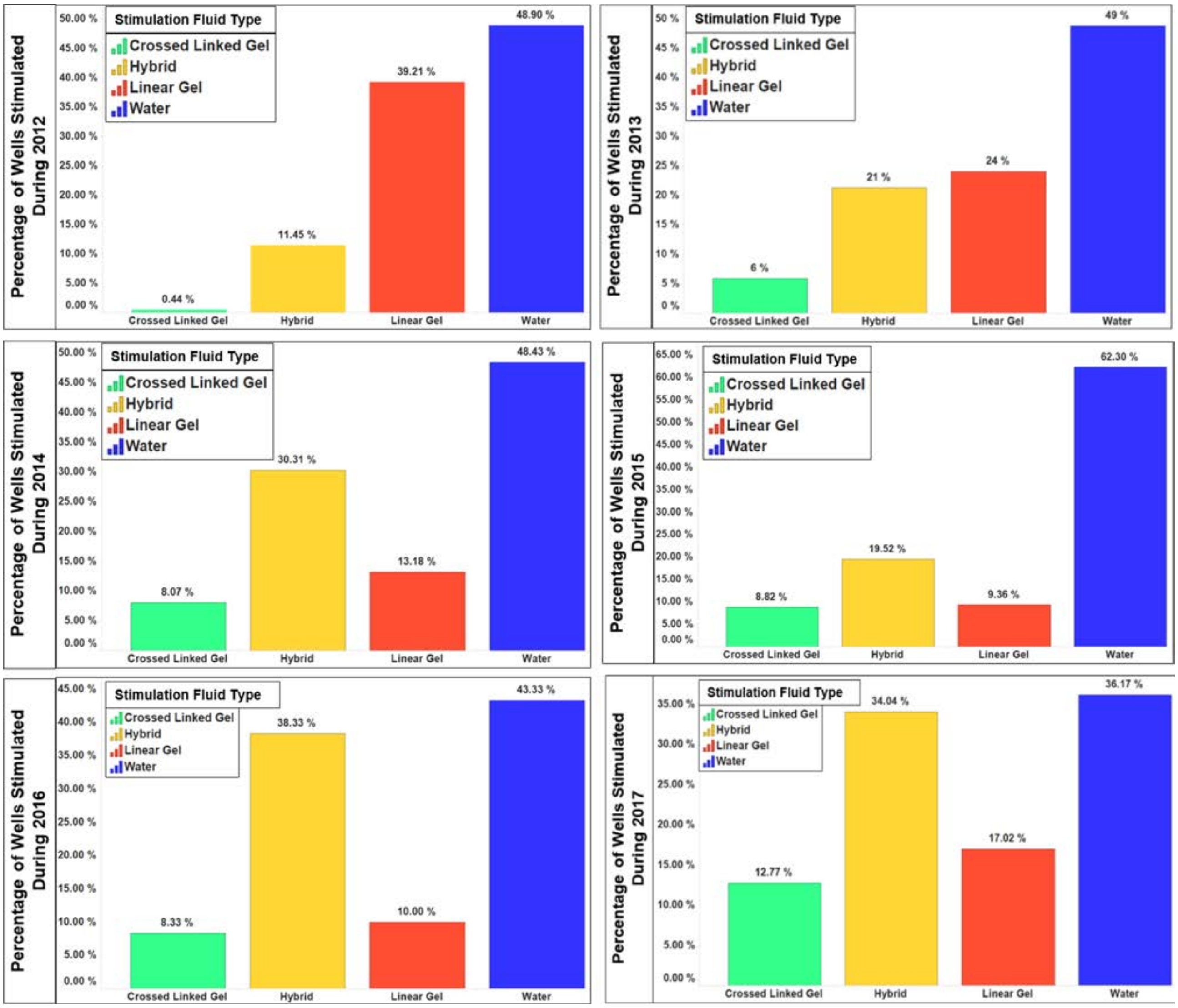

Figure 4—Number of Stimulated Wells for Each Stimulation Fluid Type in the Marcellus Shale (2012 -2018)

Results and Discussion

This section illustrates temporal changes in the types of fracturing fluids used, median water volume pumped per well and the median proppant loading per well. The section also provides the distribution values for different stimulation and completion parameters such as proppant mass pumped, water volume injected, horizontal length of the wells' lateral and the perforated segments. The perforated lateral length is used to normalize treatment volumes. Short and long term productivity response to the normalized water and proppant injected per perforated foot of horizontal lateral is presented.

Horizontal Lateral and Perforated Length Trends in the Marcellus Shale

The wells in this study were all horizontal wells with multi-stage hydraulically fracturing and producing from the Marcellus Shale. The lateral length data and the gross perforated interval (which was calculated by subtracting the upper perforation measured depth from the lower perforation measured depth) were collected from DrillingInfo. The lateral length and perforated length data were cleaned from any extreme outliers and validated using the box plots charts as indicated in Figure 5 and Figure 6. Both Figure 5 and Figure 6 show box plots superimposed by distribution diagrams of the horizontal lateral length and the gross perforated interval length, respectively. The box plots and the distribution diagrams were generated for each stimulation fluid type to show the application range of the lateral length as well as to identify and eliminate the outliers from skewing the average values of lateral length for any further analyses. Figure 7 shows box plots and distribution charts for the ratio between the perforated lateral length to the horizontal lateral length. The distribution bars indicate that most of the horizontal laterals were 70 % to 100 % perforated. In some cases, the ratio indicated more than 100% which means that the upper perforation length was extended to the build section of the well. Figure 8 shows the value of the average lateral length for each stimulation fluid type. Hybrid fluid treatments were associated with the longest average lateral lengths while water frac fluids were associated with the shortest average lateral length. Figure 9 shows the temporal change in Marcellus lateral well lengths, noted by both the average and median values of horizontal lateral and perforated lengths. The bar chart represents the average value while the line chart represents the median value of the lateral and perforated lengths. This figure shows that both the average and median values of the lateral and perforated lengths have increased every year over the time period of 2012 to 2017. The median and the average values are approximately within the same value which also indicates that the data distribution is uniform and clean of outliers which results in accurate analyses. The figure also indicates that the 88-90 % of the horizontal laterals were perforated and hydraulically fractured in the Marcellus.

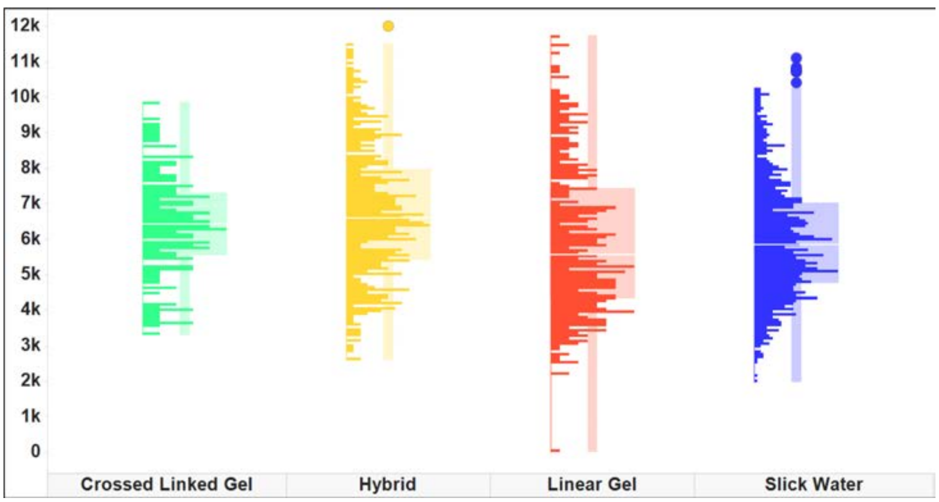

Figure 5—Box Plots and Distribution Charts of Horizontal Lateral Length (ft) of the Stimulated Wells for Each Stimulation Fluid Type in the Marcellus

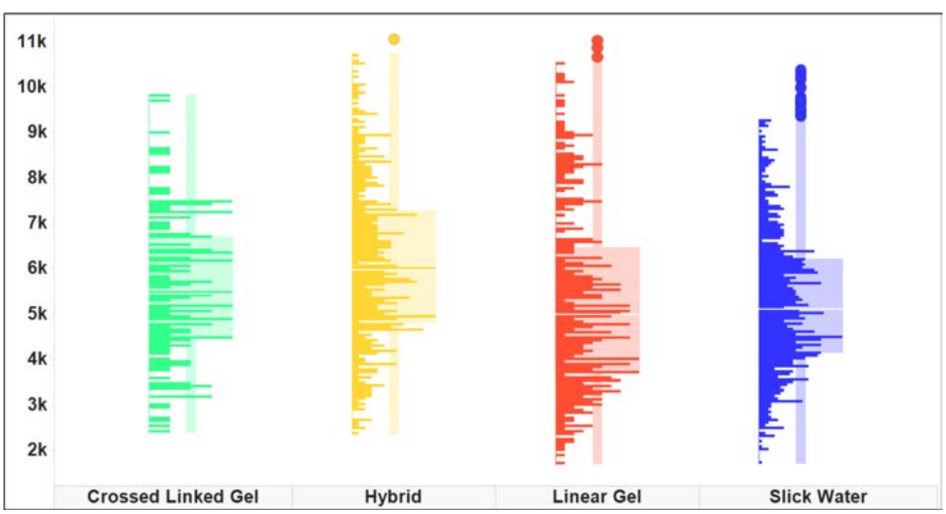

Figure 6—Box Plots and Distribution Charts of the Perfora ted Horizontal Lateral Length (ft) of the Stimulated Wells for Each Stimulation Fluid Type in the Marcellus

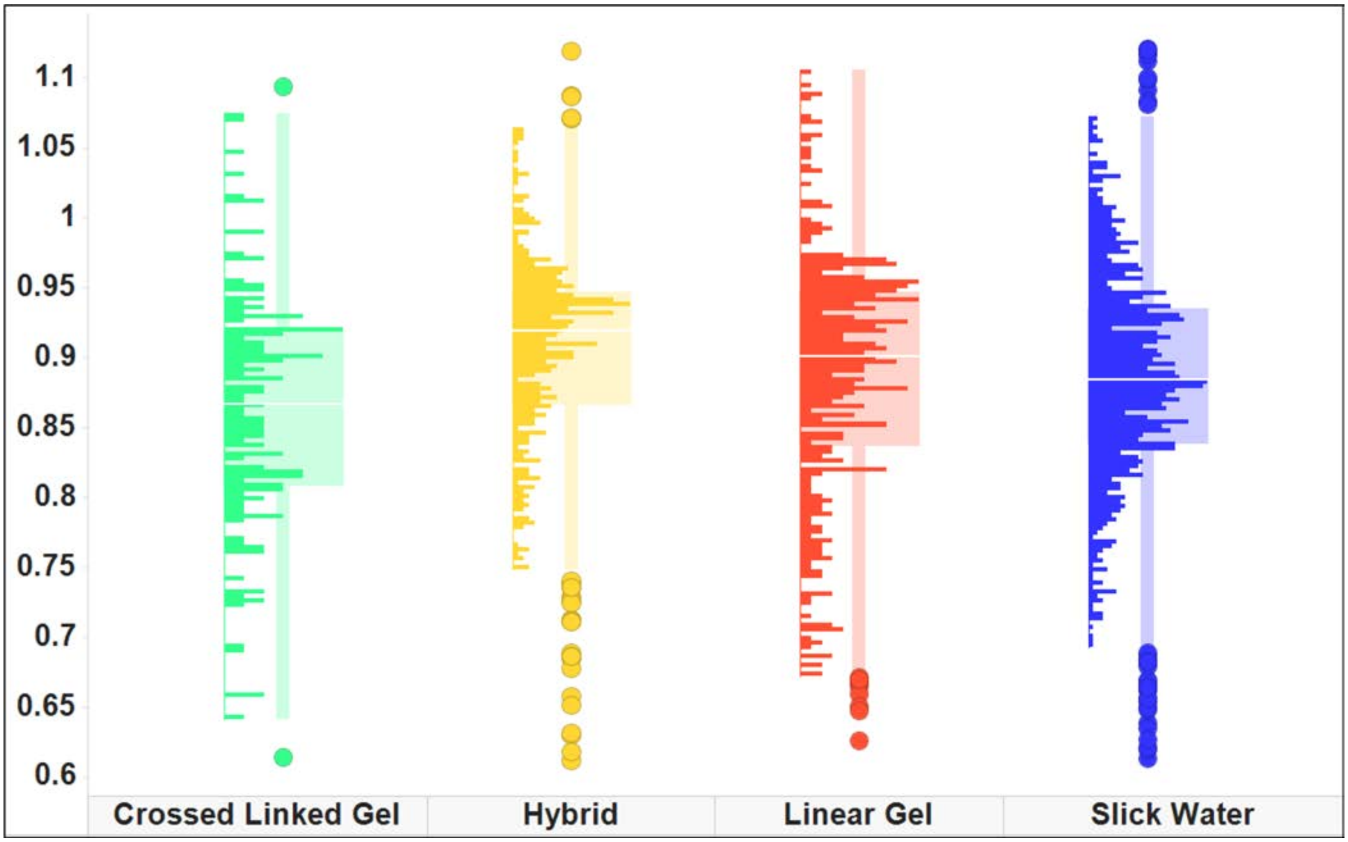

Figure 7—Box Plots and Distribution Charts of the Ratio between Perforated Lengths to the Lateral Length for Each Stimulation Fluid Type in the Marcellus

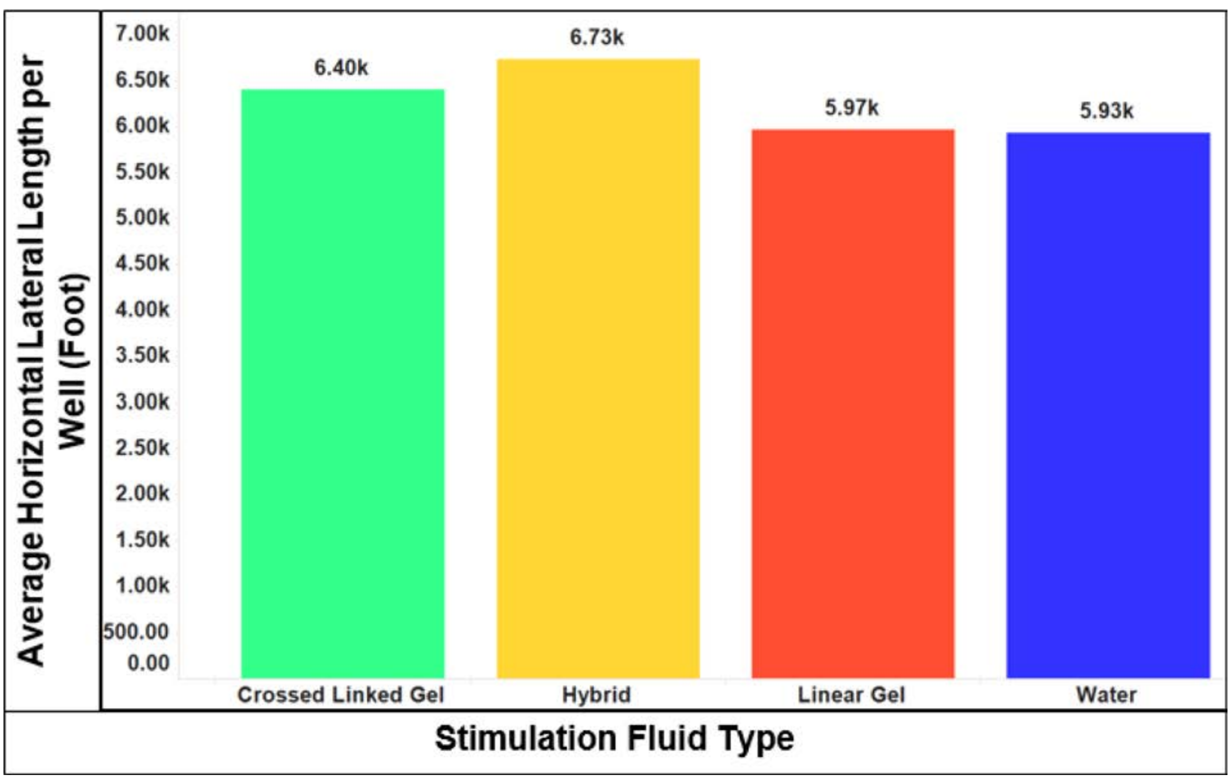

Figure 8—Bar Chart Illustrating the Average Horizontal Lateral Length for Each Stimulation Fluid Type in the Marcellus Shale

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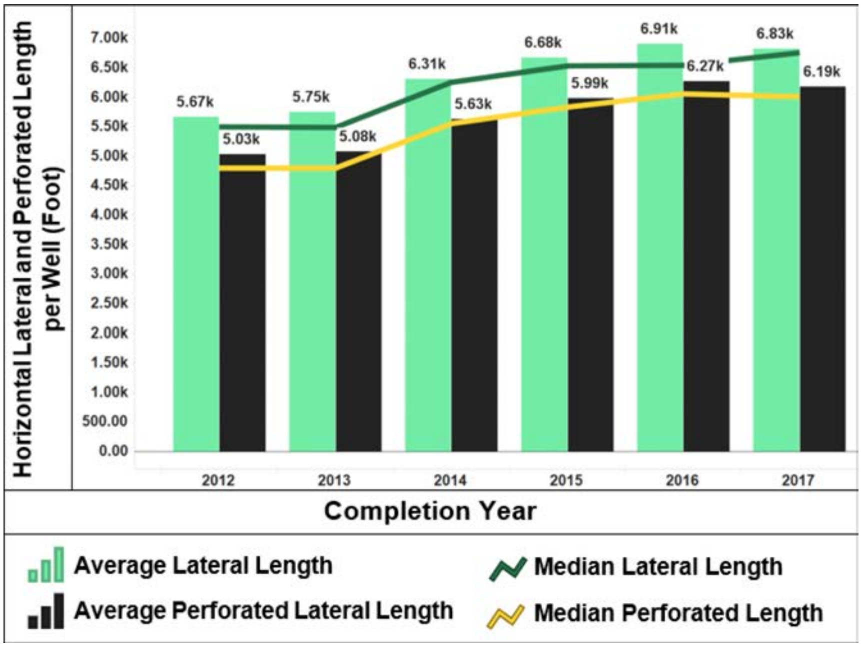

Figure 9—Combined Bar and Line Charts of Average and Median Horizontal Lateral Length and Perforated Lateral Length per Well (ft) in the Marcellus Shale

Proppant Utilization Trends in the Marcellus

To better understand the amount of pumped proppant per well in the Marcellus Shale, Figure 10 and Figure 11 were prepared to show the application range of the amount of proppant pumped per well as well as the amount of pumped proppant per stimulated lateral length for each well, respectively. The box plots show the four quartiles ranges of proppant amount and the distribution charts illustrate the number of wells that utilize the same range of pumped proppant mass. Figure 12 and Figure 13 illustrate the average and median values of the amount of proppant pumped per well over time and the normalized proppant pumped to the perforated lateral length per well over time, respectively. It can be seen that both the average and the mean values of pumped proppant per well, and the amount of proppant pumped per stimulated foot, increased throughout 2012 to 2018.

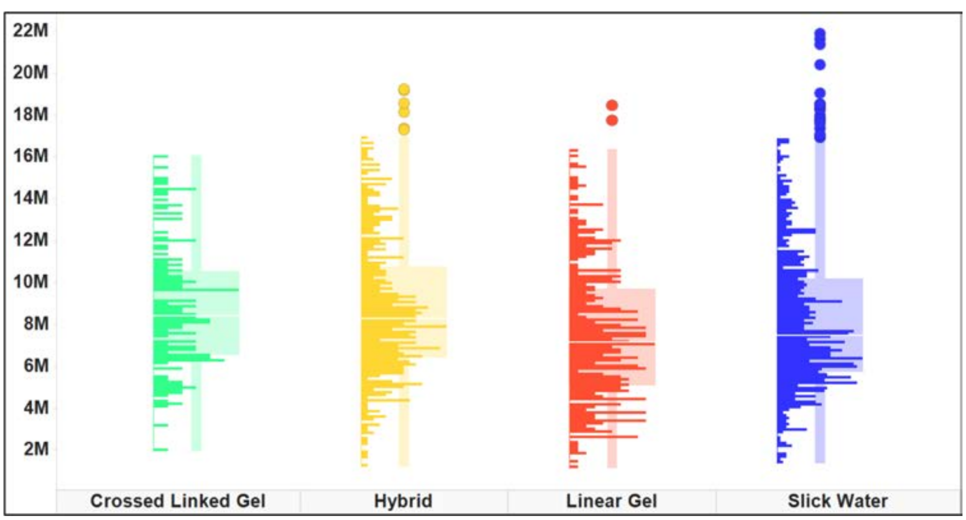

Figure 10—Box Plots and Distribution Charts of Proppant Pumped per Well (lb) for Each Stimulation Fluid Type in the Marcellus

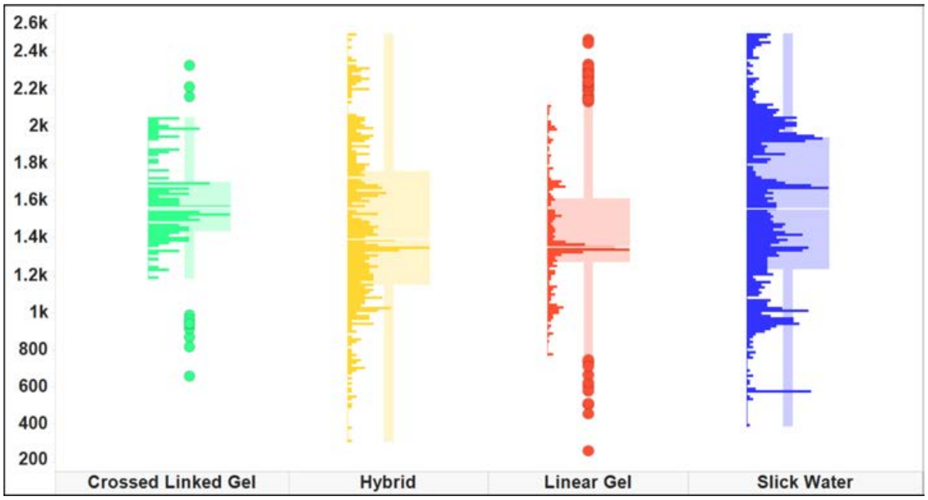

Figure 11—Box Plots and Distribution Charts of Proppant per Perforated Length (lb/Ft) for Each Stimulation Fluid Type in the Marcellus

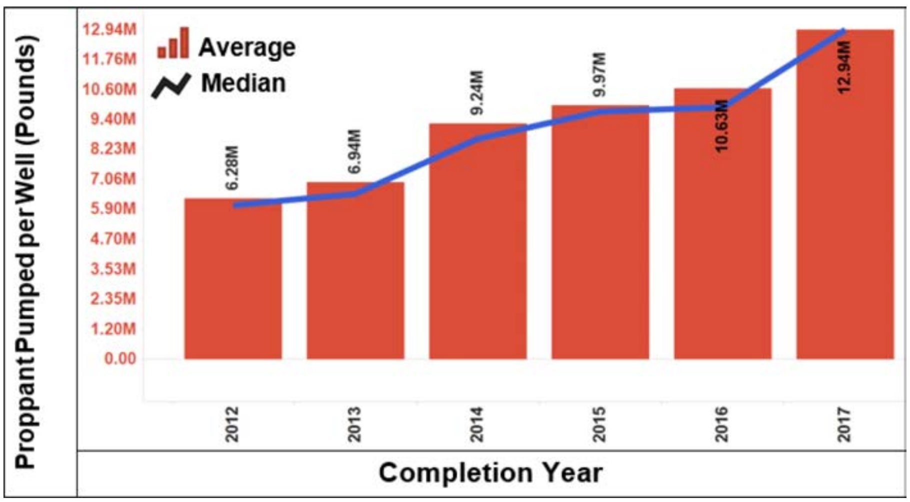

Figure 12—Combined Bar and Line Charts of Average and Median Proppant Pumped per Well (lb) in the Marcellus

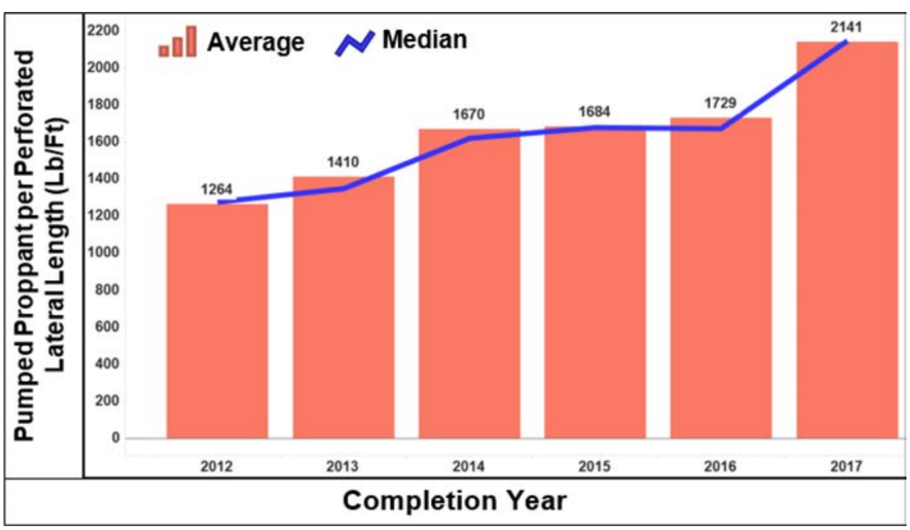

Figure 13—Combined Bar and Line Charts of Average and Median Pumped Proppant per Perforated Lateral Length per Well (lb/ft) in the Marcellus

Water Utilization Trends in the Marcellus

To better understand the volume of pumped water per well in the Marcellus Shale Figure 14 and Figure 15 were prepared to show the application range of the volume of water pumped per well as well as the volume of pumped water per stimulated lateral length for each well, respectively. The box plots show the four quartiles ranges of water volume and the distribution charts illustrate the number of wells that utilize the same value range of pumped water volume. Figure 16 and Figure 17 illustrate the average and median values of the volume of water pumped per well over time and the normalized water pumped to the perforated lateral length (gallon/foot or gal/ft) per well over time, respectively. Over the years from 2012 to 2018, both the average and the mean values showed a successive increase in the volume of pumped water per well and the volume of water pumped per stimulated foot. Figure 18 compares the average use of water and proppant per well between the wells in Pennsylvania and West Virginia. The Marcellus Shale wells in West Virginia consumed on average more water and proppant than the wells in Pennsylvania.

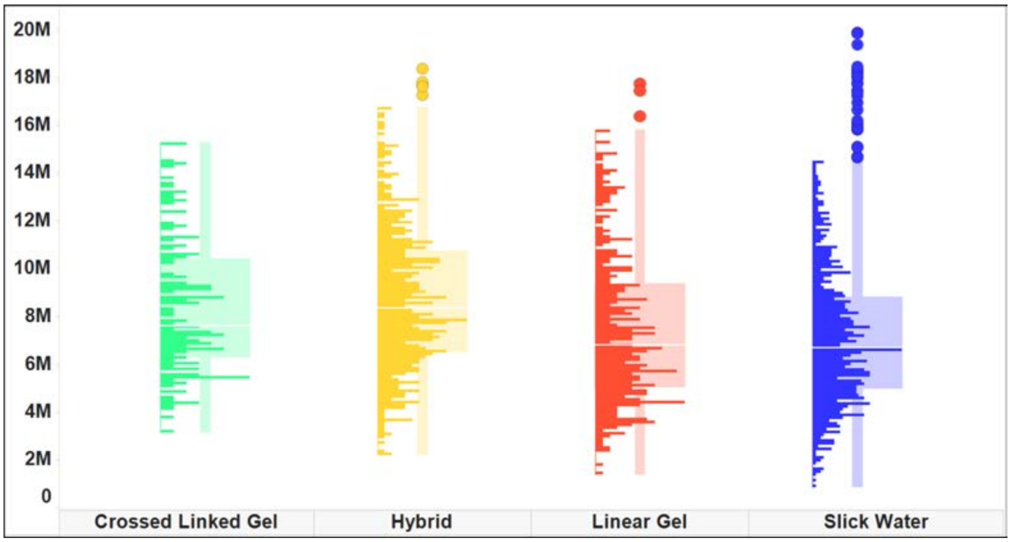

Figure 14—Box Plots and Distribution Charts of Water Pumped per Well (gal) for Each Stimulation Fluid Type in the Marcellus

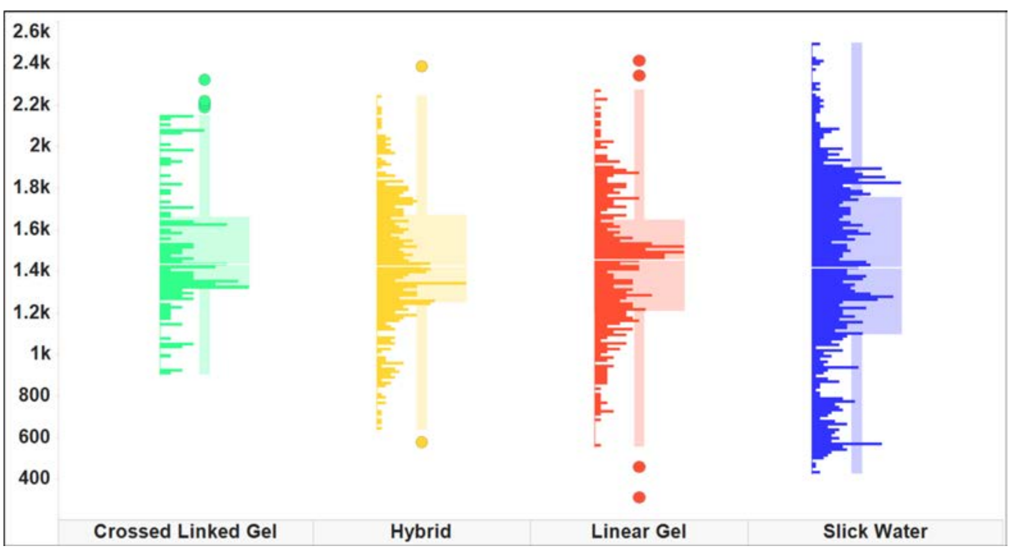

Figure 15—Box Plots and Distribution Charts of Water per Perforated Length (gal/ft) for Each Stimulation Fluid Type in the Marcellus

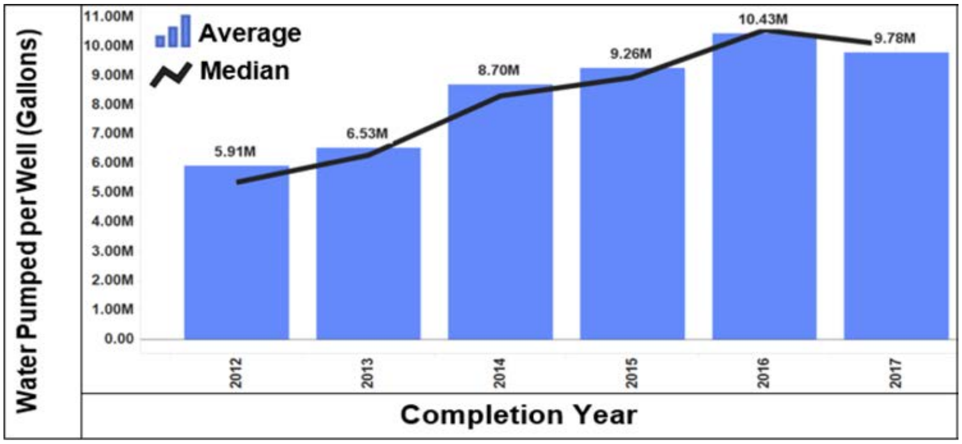

Figure 16—Combined Bar and Line Charts of Average and Median Water Pumped per Well (gal) in the Marcellus

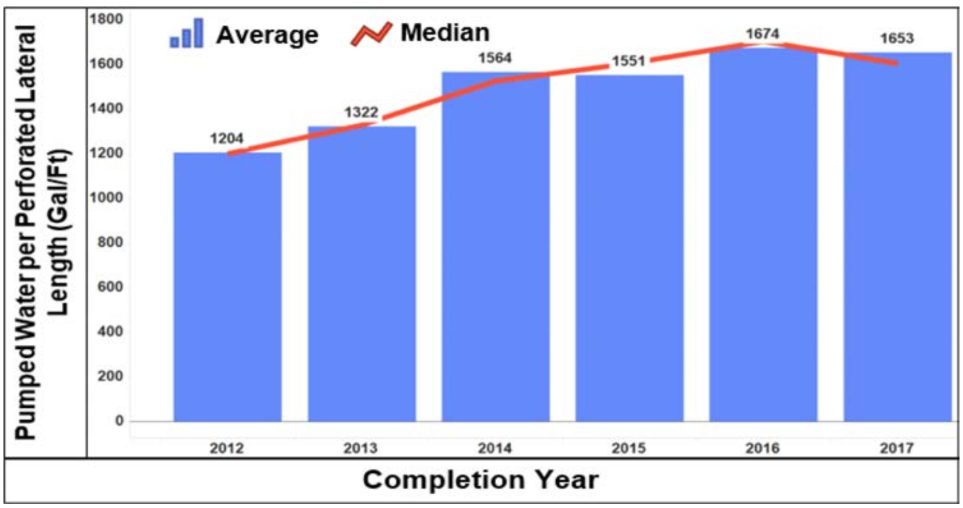

Figure 17—Combined Bar and Line Charts of Average and Median Pumped Water per Perforated Lateral Length per Well (gal/ft) in the Marcellus

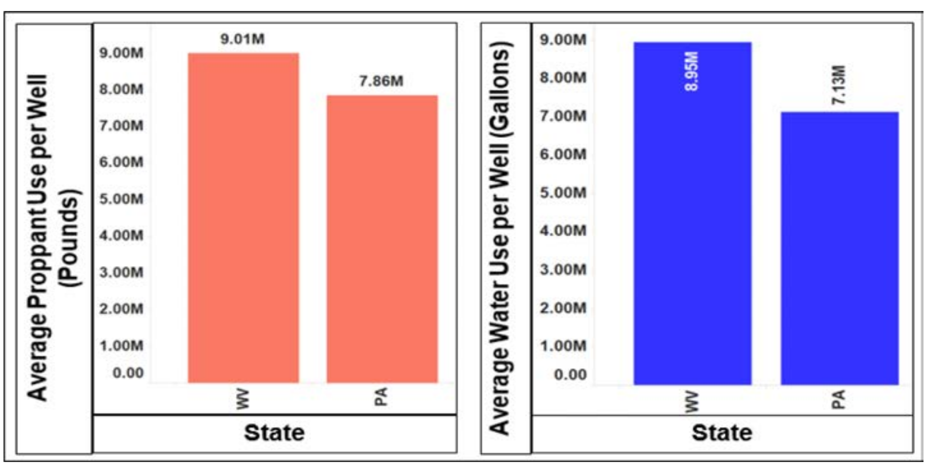

Figure 18—Water and Proppant Average Usage per the Studied States in the Marcellus

Proppant Loading Trends in the Marcellus

Proppant loading in pounds per gallon (lb/gal) is obtained by dividing the total proppant pumped mass by the total water volume pumped per well. Figure 19 shows the box plots and distribution bars of the proppant loading ranges for each stimulation fluid type. Figure 20 shows a combined bar and line charts of the average and median values of proppant loading in the Marcellus wells.

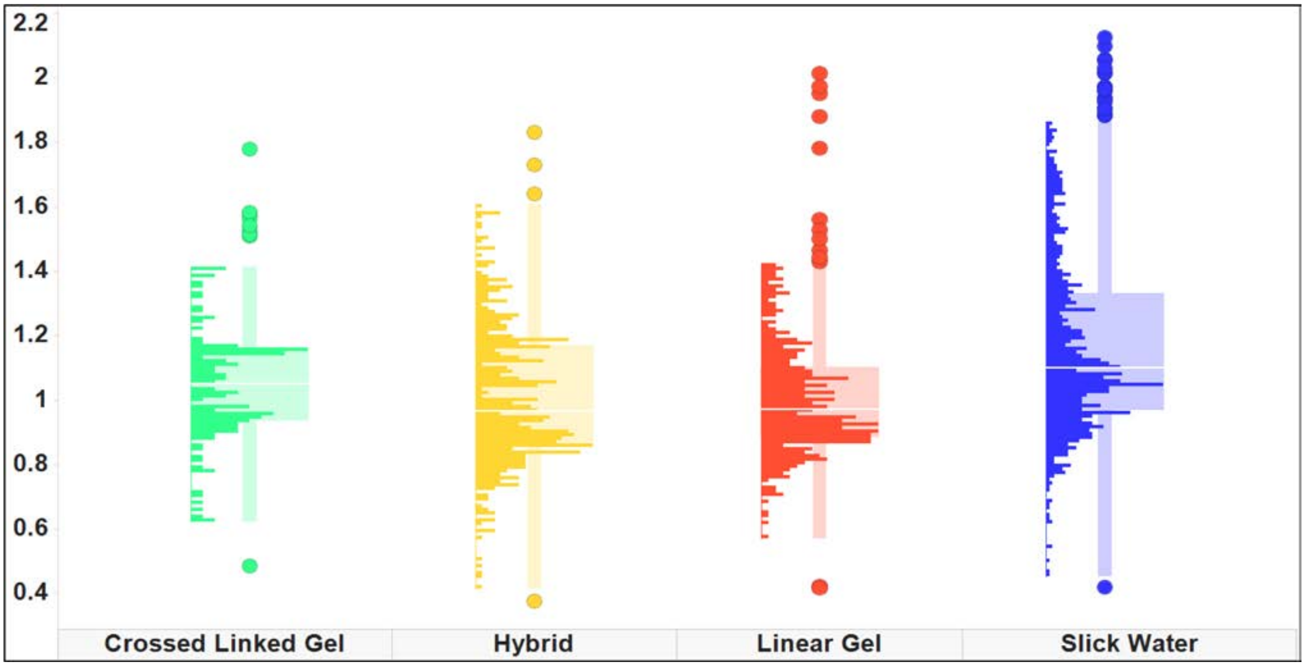

Figure 19—Box Plots and Distribution Charts of Proppant Loading (Lb/Gal) for Each Stimulation Fluid Type in the Marcellus

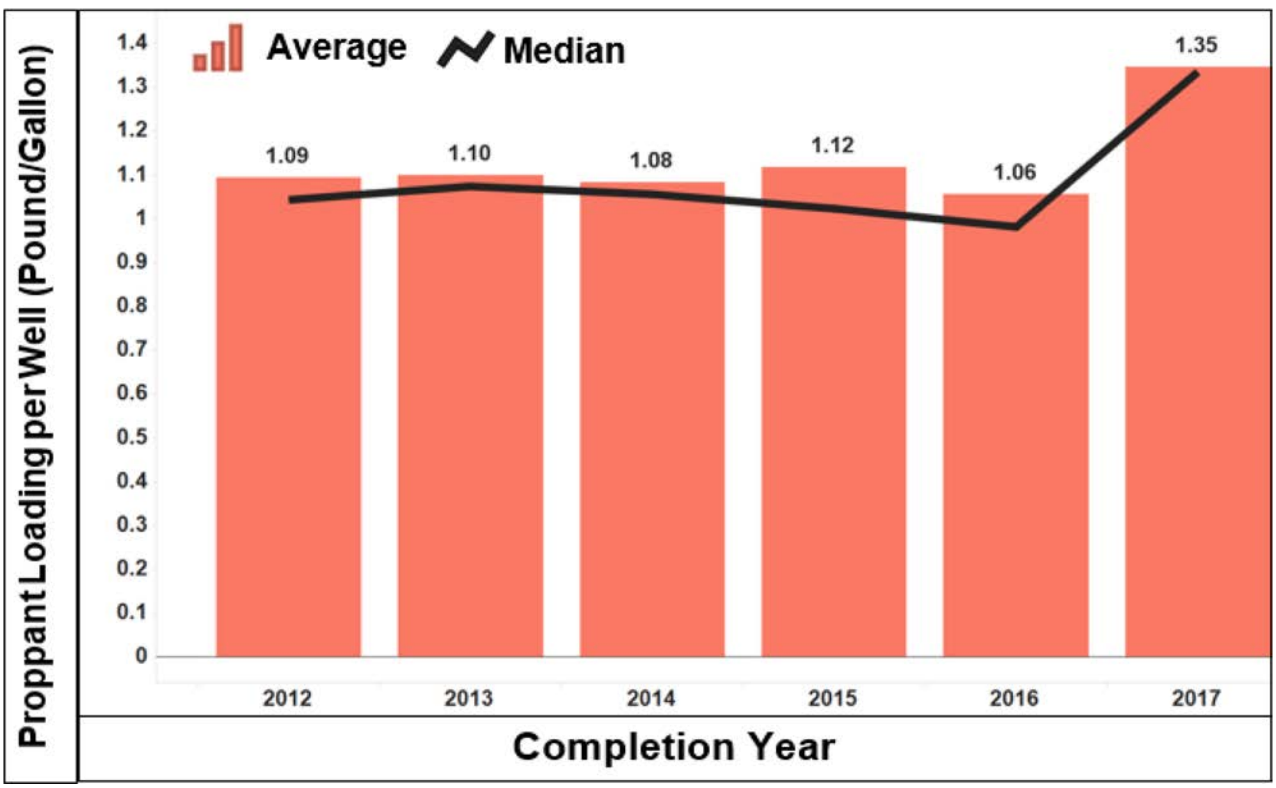

Figure 20—Combined Bar and Line Charts of Average and Median Proppant Loading per Well (Proppant/Gallon) in the Marcellus

Productivity of the Marcellus Shale Wells

Marcellus Shale production is mainly gas but to account for any liquid hydrocarbon production associated with the gas production, all production volumes have been converted to barrel of oil equivalent (BOE) using the following conversion, where each 6 MCF of gas equal 1 BOE. Figure 21 and Figure 22 illustrate the range of production in the Marcellus Shale wells in box plot charts superimposed by distribution bars for the practical initial production (BOE/day). The practical initial production was calculated by dividing the cumulative production of the second month by the number of produced days. The practical initial production is considered more representative of initial production rate because it averages the entire month of early production and avoids starting late during the first month when the well is put on production. The figures also show the cumulative BOE production for the first year, first two years, and the five years cumulative production.

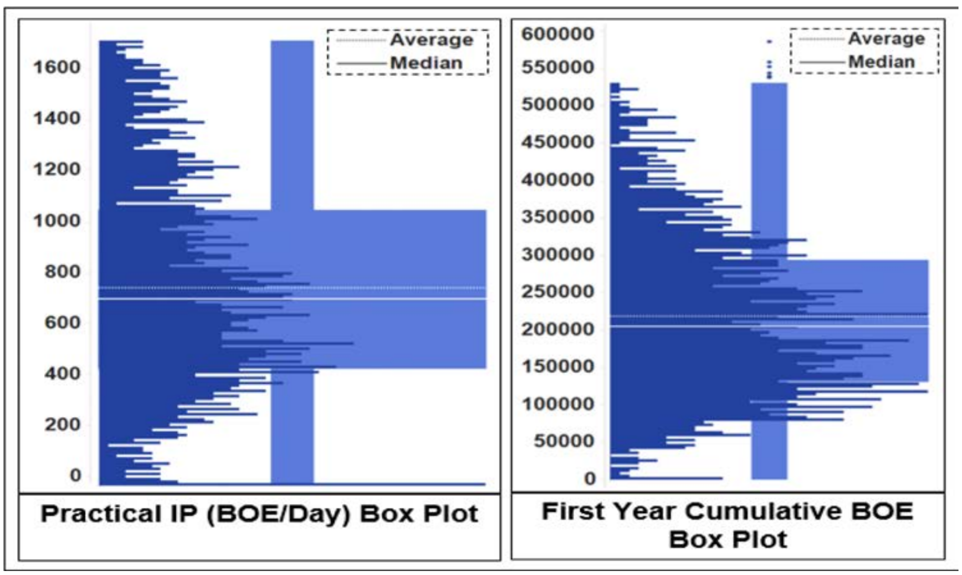

Figure 21—Box Plots and Distribution Charts of the Initial Production (BOE/ day) and First Year Cumulative Production (BOE) for the Marcellus Shale Wells

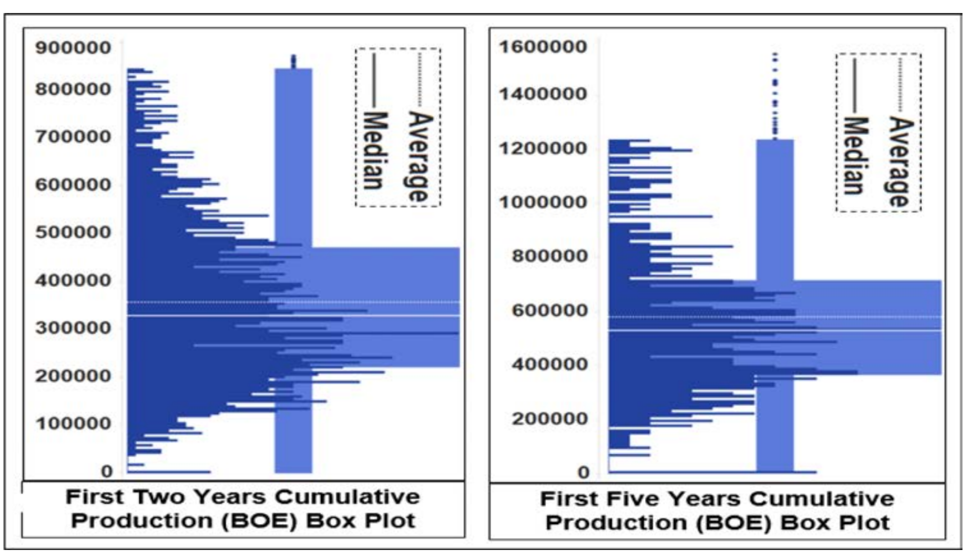

Figure 22—Box Plots and Distribution Charts of the First Two and Five Years Cumulative Production (BOE) for the Marcellus Shale Wells

Production Response to the Amount of Proppant Pumped per Stimulated Lateral Length (lb/ft)

The production performance of stimulated Marcellus wells was tested against the amount of pumped proppant per foot. The data of total proppant mass pumped per well were divided by the gross perforated lateral length (lb/ft) and grouped into five groups with increment of 500 (lb/ft). The average production performance was then plotted in a bar chart for practical initial production, first year cumulative BOE, two and five years cumulative BOE as illustrated in Figure 23, Figure 24, Figure 25, and Figure 26, respectively. The initial production response to the pumped proppant per foot showed a higher rate at the lower range of 0 – 1000 lb/ft. However, the long term cumulative production consistently showed an improvement in average annual cumulative production with higher ranges of pumped water per foot up to 2000 gallon per foot. For the high range of gal/ft (2000-2500) the average cumulative production showed a slight drop in performance which indicates that the best range of water per foot in the Marcellus Shale was 1500 – 2000 gal/ft.

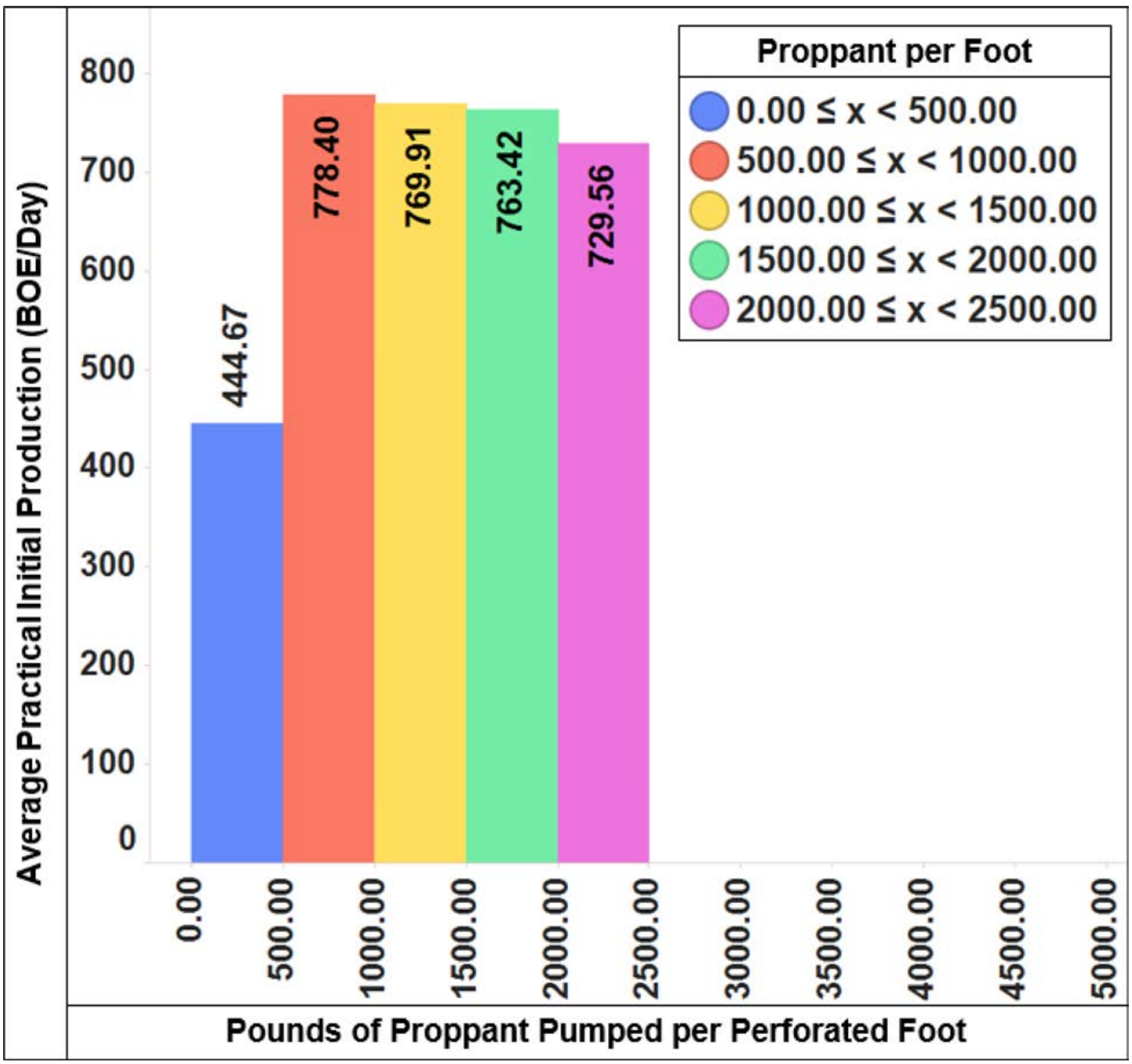

Figure 23—Proppant per Perforated Foot Effect on Initial Production in the Marcellus

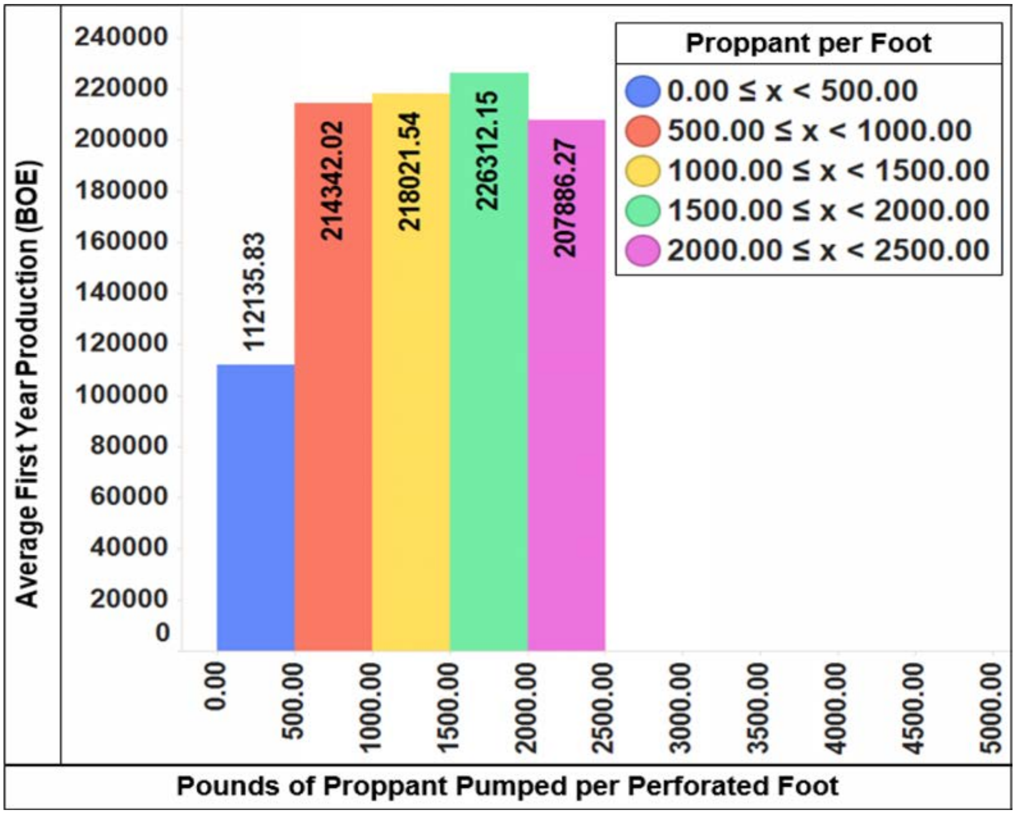

Figure 24—Proppant per Perforated Foot Effect on First Year Equivalent Production in the Marcellus

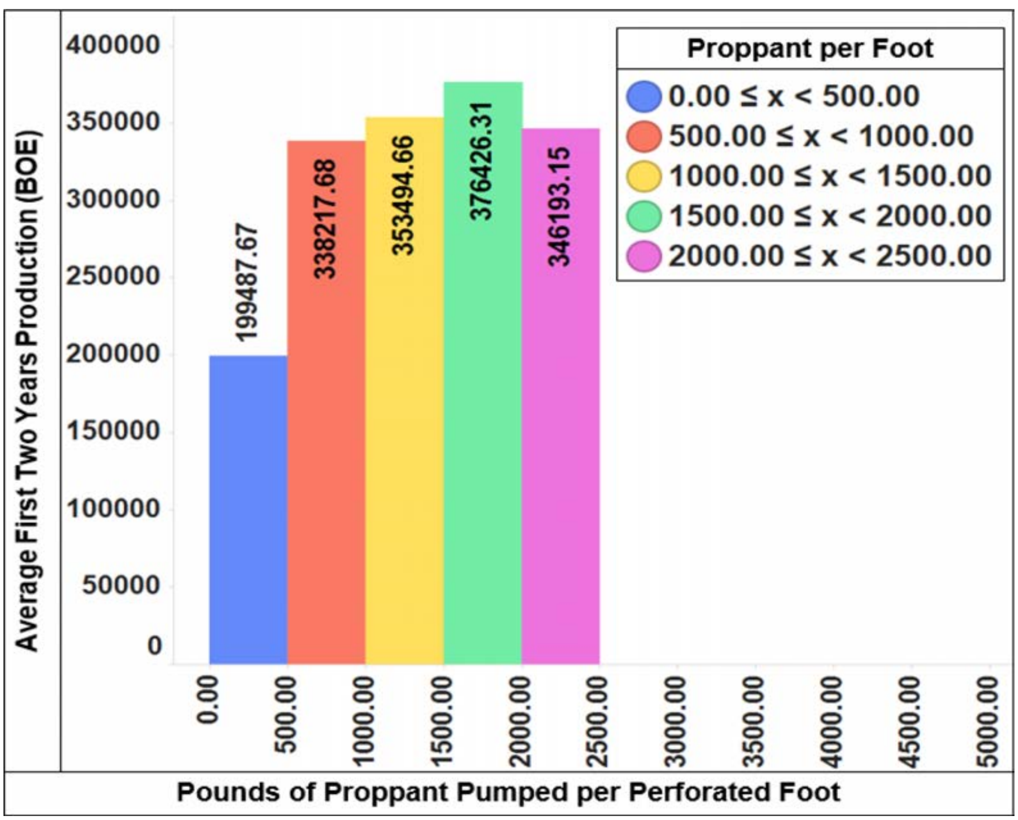

Figure 25—Proppant per Perforated Foot Effect on First Two Years Equivalent Production in the Marcellus

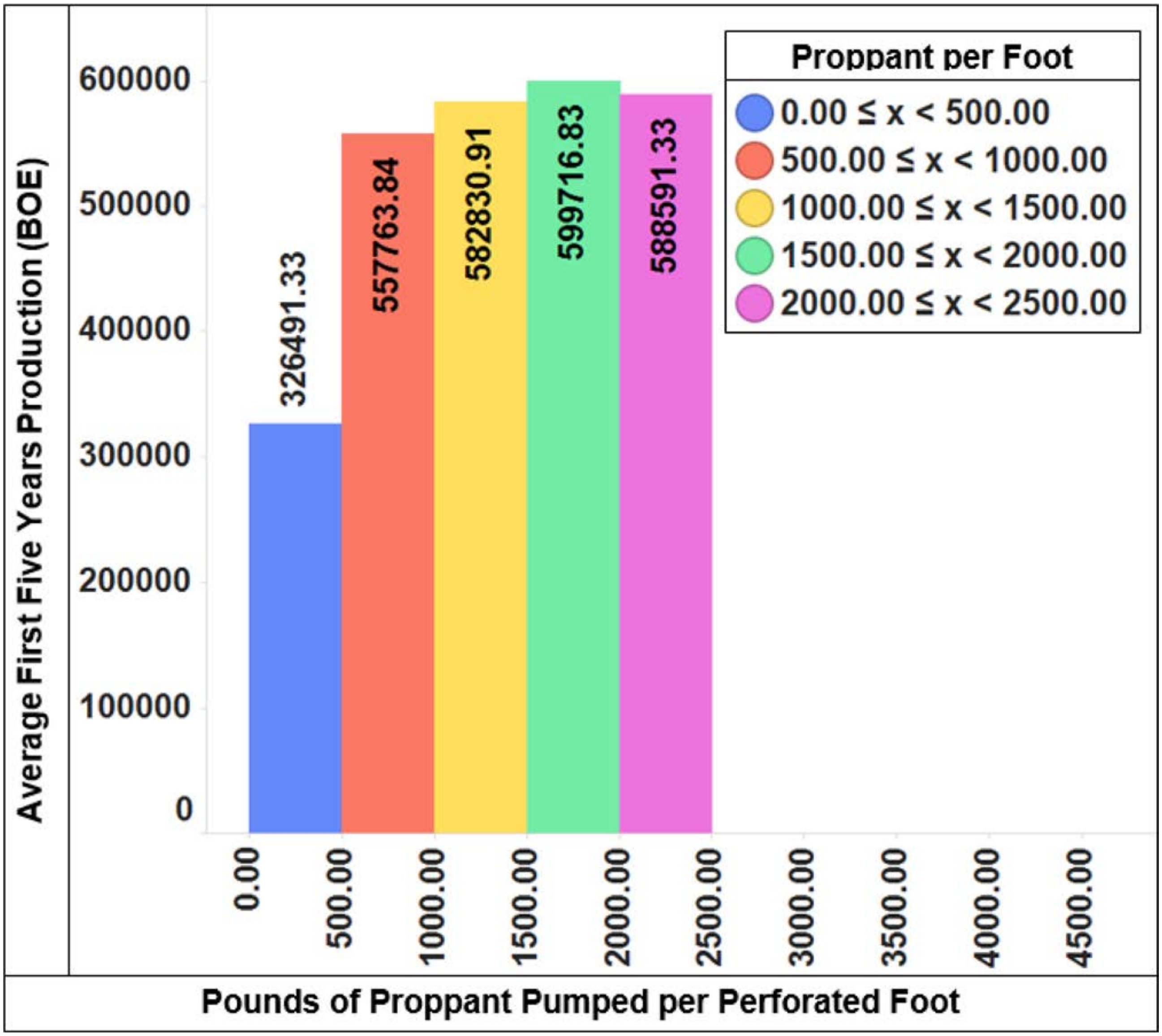

Figure 26—Proppant per Perforated Foot Effect on First Five Years Equivalent Production in the Marcellus

Production Response to the Volume of Water Pumped per Stimulated Lateral Length (gal/ft)

The production performance of the stimulated wells in the Marcellus Shale was also tested against the size of the stimulation fluid represented by the volume of pumped water per foot. The data of total water volume pumped per well were divided by the gross perforated lateral length (gal/ft) and grouped into five groups with increment of 500 (gal/ft). The average production performance was then plotted in a bar chart for practical initial production, first year cumulative BOE, two and five years cumulative BOE as illustrated in Figure 27, Figure 28, Figure 29, and Figure 30, respectively. The initial production response to the pumped water per foot showed a higher rate at the lower range of 0 – 1500 gal/ft. However, the long term cumulative production consistently showed an improvement in average annual cumulative production with higher ranges of pumped water per foot up to 2000 gal/ft. For the high range of gal/ft (2000-2500) the average cumulative production showed a slight drop in performance which indicates that the best range of water per foot in the Marcellus Shale was 1500 – 2000 gal/ft.

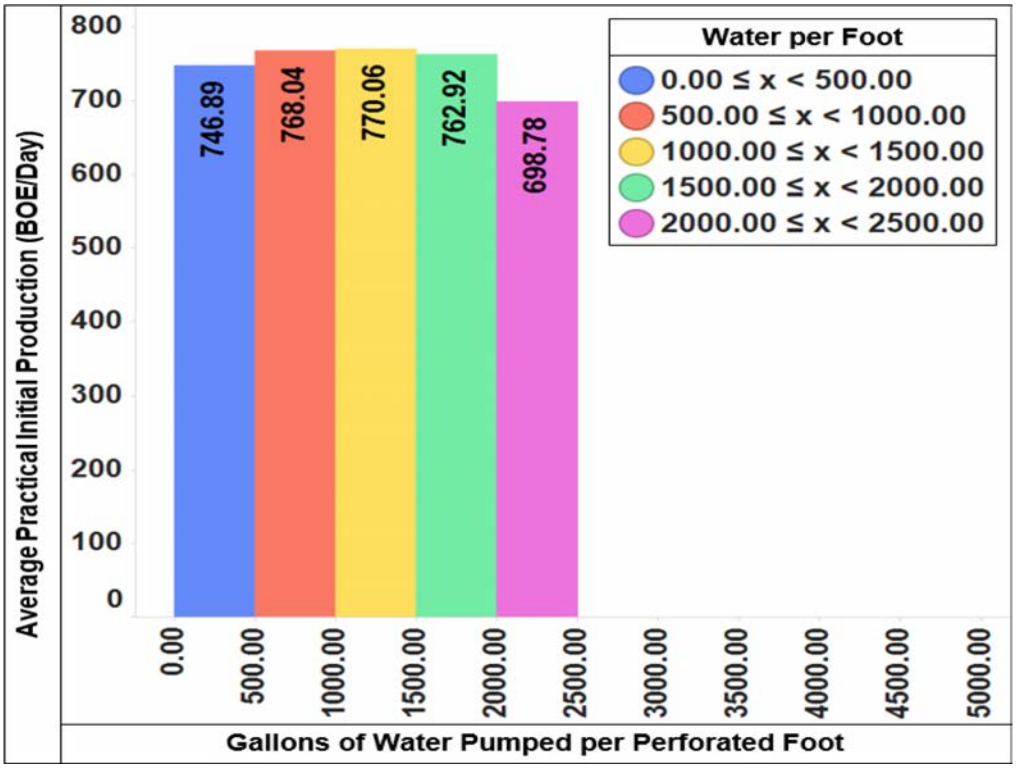

Figure 27—Water per Perforated Foot Effect on Initial Production in the Marcellus

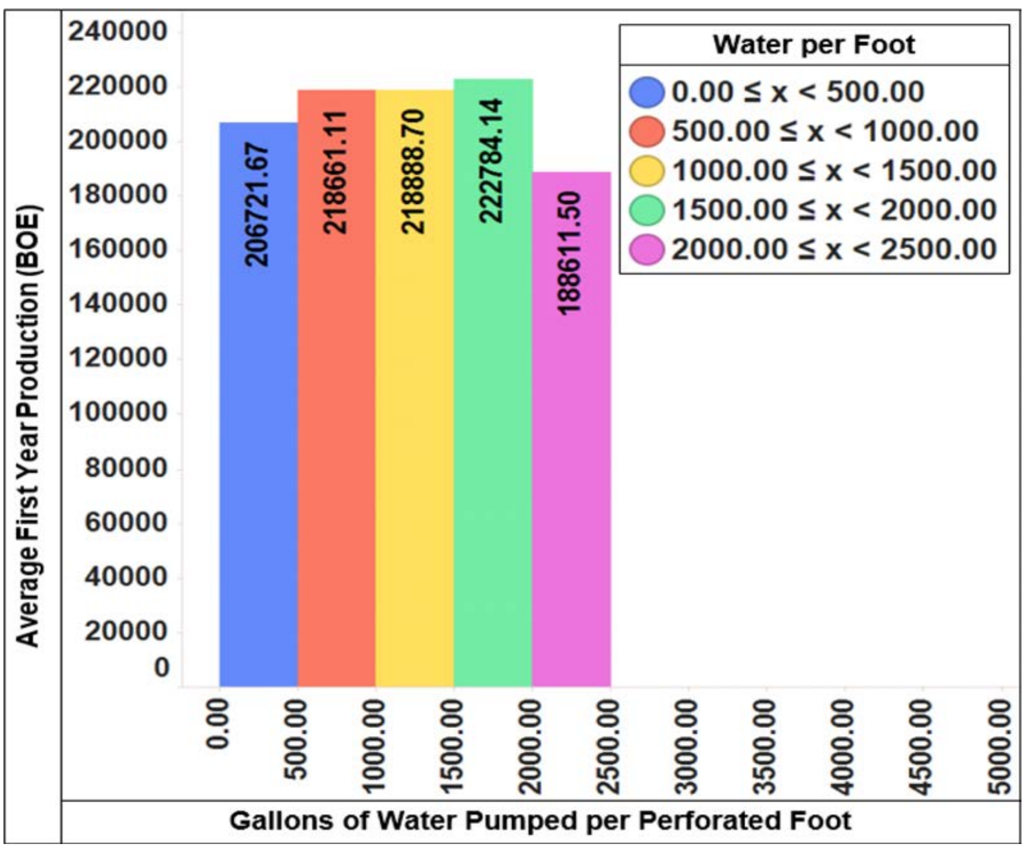

Figure 28—Water per Perforated Foot Effect on First Year Equivalent Production in the Marcellus

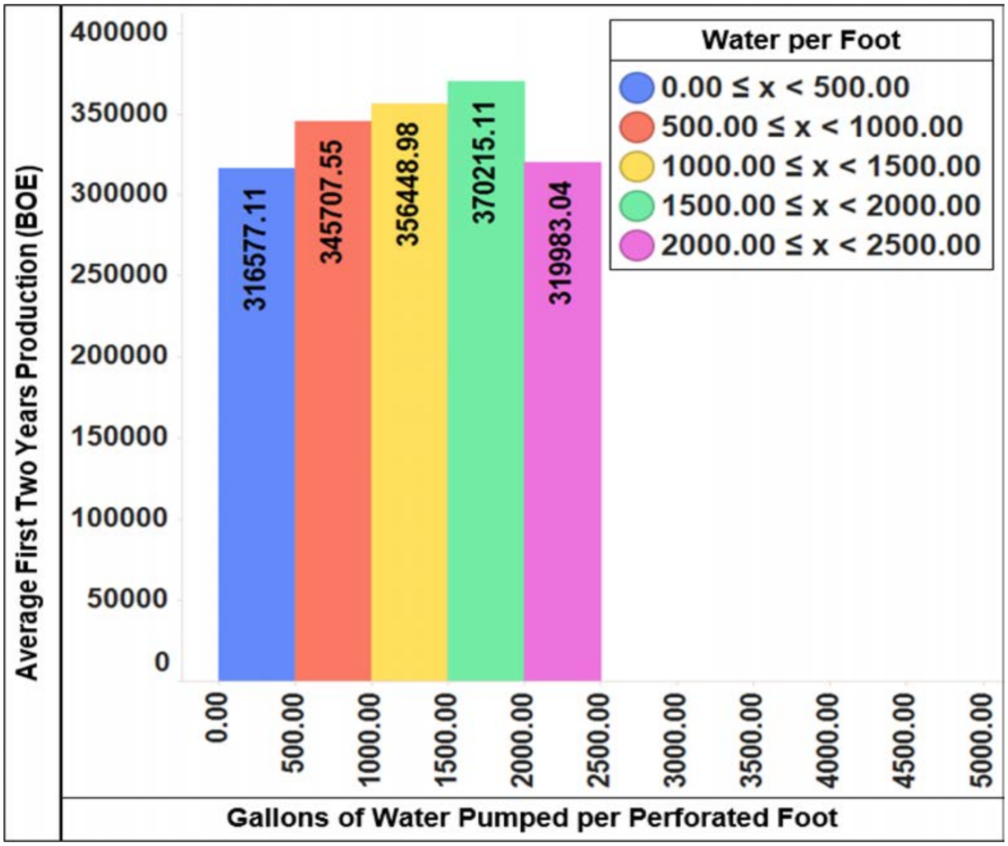

Figure 29—Water per Perforated Foot Effect on First Two Years Equivalent Production in the Marcellus

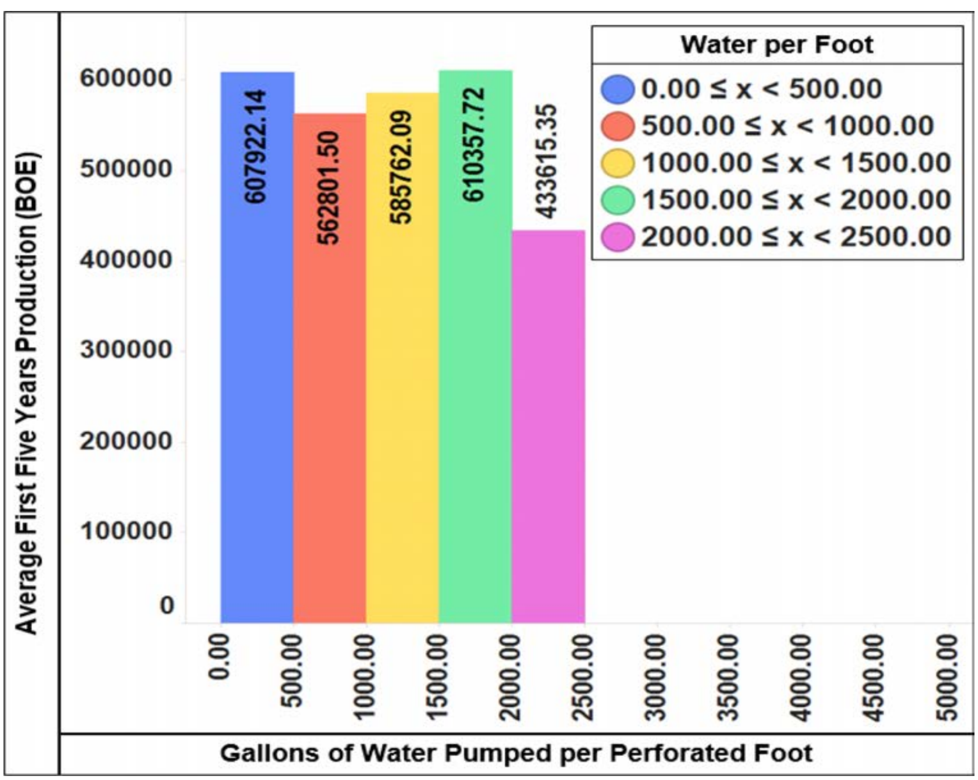

Figure 30—Water per Perforated Foot Effect on First Five Years Equivalent Production in the Marcellus

Conclusion

In this study, a comprehensive database for the Marcellus Shale play was created by extracting and processing fracturing fluids chemical ingredients from FracFocus and then integrated with production and completion data acquired from DrillingInfo. The database was used to create a descriptive analysis approach to gain insights and understand the trends of stimulation parameters of proppant mass, water volume, proppant to water ratio (proppant loading), horizontal lateral length, and the perforated interval length of the laterals. The production performance of the wells was also introduced in this study by comparing the size and the amount of pumped water and proppant per the stimulated lateral foot. The main conclusions of this study are summarized in the points below:

- The chemical registry of FracFocus 3.0 can be utilized as a practical source of chemical ingredients for most of the wells stimulated after 2012. The raw data from FracFocus need to go through rigorous cleaning and processing workflows to generated usable and insightful parameters to be used in descriptive and predictive analytical approaches.
- The hydraulic fracturing process and chemical ingredients subject matter expertise are paramount to successfully utilize FracFocus data and to present insights into the stimulation and completion trends in any unconventional shale play development.
- In the Marcellus Shale wells, more than 50% of the stimulated wells were stimulated with water fracturing fluids.
- About 90% of the horizontal lateral length was perforated and stimulated in the Marcellus wells.
- Studying the proppant and water quantities trends over time showed that every year the operators in the Marcellus have increased the average size of the fracturing fluids water base volume and the amount of the associated proppant.
- Testing the productivity of the wells indicated that the long term cumulative BOE production in the Marcellus Shale wells positively increased as the amount of pumped water and proppant per foot was increased. Pumping more than 2000 pound per foot of proppant or 2000 gallon per foot of water indicated a negative trend in term of cumulative production.

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