

Fort Worth Basin/Barnett Shale Natural Gas Play: An Assessment of Present and Projected Fresh Water Use



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Executive Summary

The Barnett Shale of the Fort Worth Basin is the largest natural gas field in Texas and the second largest in the United States. The field covers 20 counties in North Texas, including the Fort Worth metropolitan area. There are more than 6,400 wells in the field producing more than 2 billion cubic feet (BCF) per day or roughly 10% of the natural gas produced in Texas and 3% of U.S. natural gas production. To date, the Barnett Shale has produced more than 2.5 trillion cubic feet (TCF). According to a 2004 report by the U.S. Geological Survey, the Barnett Shale had an estimated 27 trillion cubic feet (TCF) in natural gas reserves (enough gas to heat 10 million homes for 27 years). The Barnett Shale has been a major economic driver both on the state and local levels generating billions of dollars a year in economic output, including expenditures for development activities, salaries, state and local taxes, lease bonus and royalty payments, and other expenses.

The use of fresh water is critical for natural gas producers operating in the Barnett Shale of the Fort Worth Basin. The Barnett Shale play has experienced rapid growth over the last few years and will likely remain an active growth area for the next twenty years or more. As a consequence, the industry faces mounting costs, logistical challenges and public relations concerns over the potential magnitude of fresh water use. Such concerns are exacerbated by the extended drought which the region has experienced over recent years. The drought has reduced the storage of surface water in reservoirs, further stressed groundwater aquifer storage and increased the demand on groundwater resources. These factors have created a perception among many that gas producers threaten both surface water and groundwater supplies in the Fort Worth Basin.

This assessment was commissioned by the Barnett Shale Water Conservation and Management Committee (BSWCMC or the “Committee”) and performed under the direction of the Gas Technology Institute (GTI) to gather data on the present and future fresh water consumption by Barnett Shale natural gas producers. This study involved an analysis of actual and projected demands on surface and groundwater resources to determine if competition for fresh water supplies in the Fort Worth Basin will significantly constrain Barnett Shale natural gas development. The Committee is also trying to determine if technological options can potentially mitigate future demands for fresh water resources by the natural gas industry.

The present and projected freshwater demands by Barnett gas producers are small, relative to that of other users considered over the entire Barnett play. Although there has been significant growth in natural gas development in the Barnett Shale area, natural gas well development use of both surface and groundwater was less than 1 percent of total fresh water use in 2000 and in 2005. The amount of groundwater use associated with gas well development in the Barnett Shale presently accounts for about 3 percent of the total groundwater use in the study area.

It is projected by the Texas Water Development Board that even under a high Barnett drilling activity scenario, Barnett operators will require less than 1% of surface water supplies and less than 10% of groundwater supplies in 2010, the year that Bureau of Economic Geology predicts Barnett drilling activity will peak. When averaged over the entire Barnett shale play, the proportionally small demand by Barnett operators on surface water supplies indicates no reason for concern. However, it is important to note that the Trinity aquifer thins out toward the western part of the basin, indicating that there will be less groundwater available for extraction. Therefore, near the western margin of the Trinity aquifer, and in localized areas of certain counties where well yields are limiting, projected increases in the proportional groundwater demand for natural gas drilling and completion indicate the need for due diligence and pro-active water resource planning. As a rule, the yield (flow rate) of individual water wells is generally correlated with the in-place groundwater supply; therefore, marginal areas of the Trinity aquifer will generally only support limited groundwater extraction rates. Where water well yields are below a certain threshold (50 gallons per minute), these areas will likely not have the groundwater supplies necessary to support substantial natural gas development; thus, gas operators will of necessity look to other sources.

Barnett gas producers are presently active in researching and testing evolving technologies for reducing their net freshwater consumption. Pilot-scale research on flow-back water treatment and recycling presently underway by Devon Energy and Encana has shown that some fraction of flow-back water can be treated and recycled, but it is not yet clear whether large scale recycling will be economically viable.

Acknowledgements

The author would like to gratefully acknowledge the following individuals and organizations who assisted with this project: Barnett Shale Water Conservation and Management Committee members (and the other companies cited in Appendix A) who provided data on fresh water use for natural gas drilling and well completion; Robert Mace, Cindy Ridgeway and Ali Chowdbury of the Texas Water Development Board who provided access to their publicly available data on Fort Worth Basin water resources; Jean-Philippe Nicot of the Texas Bureau of Economic Geology who provided data and professional insight on Barnett shale development and groundwater demand; and Robert Harden of Harden and Associates, Inc. who provided data and the site map used in this report.

The author would also like to express his appreciation for the review and editorial recommendations provided by Tom Hayes of the Gas Technology Institute, Barnett Shale Water Conservation and Management Committee members, Gene Montgomery of the Texas Oil and Gas Association and Robert Mace of the Texas Water Development Board. Any errors or omissions thus remaining are the sole responsibility of the author.

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Fort Worth Basin/Barnett Shale Natural Gas Play: An Assessment of Present and Projected Fresh Water Use

Introduction

The use of fresh water is critical for natural gas producers operating in the Barnett Shale of the Fort Worth Basin. The Barnett Shale play has experienced rapid growth over the last few years and will likely remain an active growth area for the next twenty years or more. The industry faces mounting costs, logistical challenges and public relations concerns over the potential magnitude of fresh water use. Such concerns are exacerbated by the extended drought which the region has experienced over recent years. The drought has reduced the storage of surface water in reservoirs, further stressed groundwater aquifer storage and increased the demand on groundwater resources. Fresh water used for natural gas development is often stored in large surface impoundments. As gas development has moved into more urban areas, the general public has become aware of the oil and gas industry's use of fresh water. These factors have created a perception among many that gas producers threaten both surface water and groundwater supplies in the Fort Worth Basin.

In response to these concerns, Barnett gas producers formed the Barnett Shale Water Conservation and Management Committee¹ (BSWCMC or the "Committee") in March of 2006. The Committee is a consortium of Barnett gas producers whose mission is to develop best water management practices to ensure that fresh water is conserved and managed in an efficient and responsible manner. The Committee has retained the Gas Technology Institute² (GTI) to coordinate its meetings and activities. The work presented in this report is the first project directed by GTI for the Committee.

In August of 2006, the Texas Water Development Board (TWDB) initiated a study of groundwater use and availability in the Trinity and Woodbine aquifers, which underlie and serve most of the Fort Worth Basin. The objective of their study was to evaluate the projected groundwater demands by Barnett gas producers and other users, and to determine if these have the potential to diminish groundwater supplies. TWDB published their study in February, 2007 (Bene et al., 2007). The Committee assisted in the study by providing Bene et al. (2007) with information fresh water use for natural gas development.

This report represents a summary and synopsis of information on fresh water use by Barnett gas producers and others in the Fort Worth Basin; (see Figure 1 – Study Area, and Appendix C for the list of counties encompassed in this study.). The scope of this work encompassed an analysis of fresh water use and of technological options that may mitigate the demand for fresh water resources by the natural gas industry. This work is based upon information published by the Barnett Shale Water Conservation and

¹ A list of active Committee members is given in the Appendix.

² See: www.gastechnology.org .

Management Committee (the “Committee”), the Texas Water Development Board, the Texas Bureau of Economic Geology (BEG), and the Texas Railroad Commission (RRC).

Approach

The starting point for this work was to evaluate the current fresh water use by Barnett Shale gas producers. Toward this end, GTI initiated a survey of fresh water use by Barnett natural gas producers in June, 2006. This survey provided information on the quantities of fresh water used to drill and complete new gas wells in the Barnett play, broken down by well type (horizontal versus vertical), and source (surface water versus groundwater). The survey encompassed historical data for 2005 and 2006, with projections for 2007. A total of 16 companies (Committee member companies and others) representing an estimated 80% of Barnett drilling activity responded to the survey³, which entailed completing a spreadsheet data template and responding to various follow-up questions. A summary of the data survey is provided in Appendix C. This survey thus represents a current and definitive characterization of key gas industry water use parameters.

The next step in this project was to compare fresh water use by Barnett gas producers to that of other water users in the Fort Worth Basin. These comparisons were made in light of what is known on the availability of groundwater and surface water resources. The sources of information for these analyses were the report, cited previously, and information from other State of Texas agencies.

Finally, a brief analysis of the potential for reducing fresh water demand by Barnett gas producers was performed. This entailed a summary of re-use options, possible alternate water resources, and present on-going research.

³ See Appendix for list of participating companies.

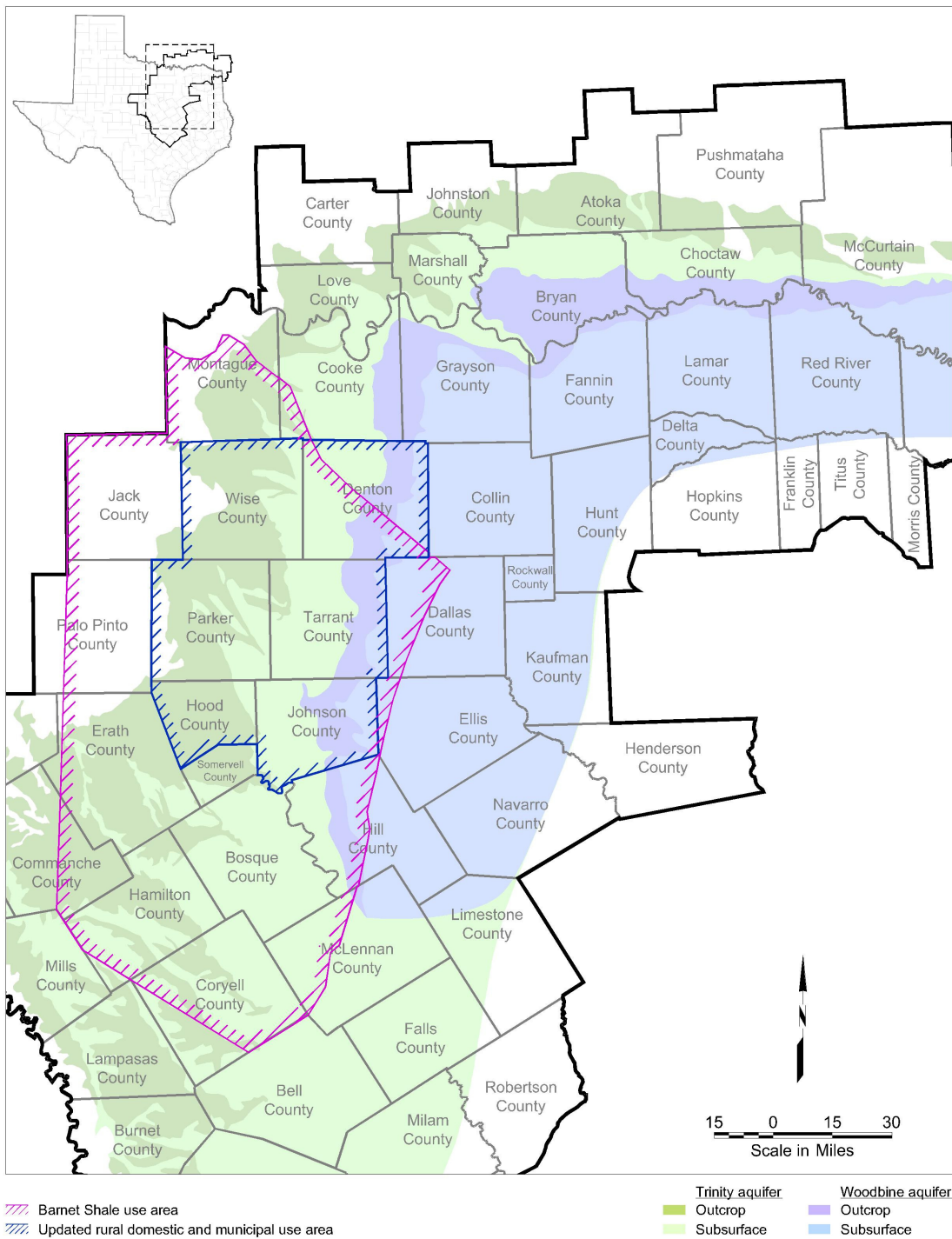


Figure 1 - Study Area⁴ (...within the "hatched" polygon).

⁴ Taken and used with permission from R.W. Harden & Associates, Inc. in Bene et al. (2007).

Barnett Gas Producers' Fresh Water Use

Results of the GTI survey are given in aggregate over all counties in the Fort Worth Basin where Barnett drilling is active. Approximately 80% of industry activity in the Barnett play is represented in this survey, based upon an estimated total number of well completions of approximately 1,500 for the basin in 2006 (Figure 2).

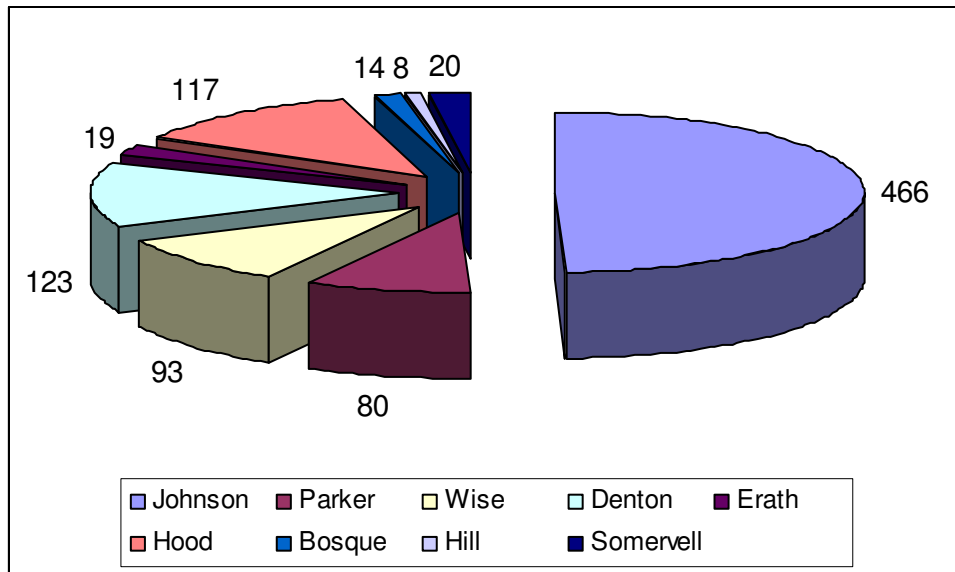


Figure 2 – Barnett well completions reported by county in the GTI survey for 2006. The total of 1202 reported in the survey represents approximately 80% of total Barnett activity, based upon an estimated total of 1500 well completions for that year.

Survey results (Table 1) indicate that approximately 90% of drilled wells in 2006 were horizontal, and that the average fresh water use in horizontal well completion was approximately 9.4 acre-feet (3.05 million gallons)⁵. In contrast, average fresh water use for completion of vertical wells was approximately 6 acre-feet (1.96 million gallons). As the Barnett gas play continues to develop, it is likely that horizontal wells will predominate as indicated by the survey results.

It is noted that the average fresh water use to complete each horizontal well decreases between the years of 2005 to 2007. This is primarily due to the thinning of gas productive zones in the Barnett shale as the play expands beyond its core areas. In contrast, the increase in fresh water use for vertical wells reflects the development of more aggressive completion techniques. However, the relative fraction of vertical wells is presently small (approx. 10%) and will likely further diminish as the Barnett play develops.

⁵ One acre-foot is equivalent to 325,829 gallons

Table 1 - Results of fresh water use survey from Barnett gas producers: raw data.

| | 2005 | 2006 | 2007 |
|------------------------------------------------------|-------------|-------------|-------------|
| # Drill rigs (approx.) ⁶ | 57 | 93 | 112 |
| # Wells drilled | 713 | 1,202 | 1,504 |
| # Horizontal | 590 | 1,093 | 1,401 |
| # Vertical | 123 | 109 | 103 |
| % Horizontal | 83 | 91 | 93 |
| % Vertical | 17 | 9 | 7 |
| Avg horizontal well water use (million gallons/well) | 3.2 | 3.0 | 2.9 |
| Avg horizontal well water use (ac-ft/well) | 9.79 | 9.38 | 8.84 |
| Avg vertical well water use (million gallons/well) | 1.7 | 2.0 | 2.0 |
| Avg vertical well water use (ac-ft/well) | 5.35 | 6.02 | 6.24 |

Extrapolating the 2006 GTI survey statistics to all of drilling activity in the Fort Worth Basin, it is estimated that approximately 13,608 acre-feet of water were used for gas well drilling and completion in 2006; (Table 2). An estimated 56% of this (7,688 acre-feet) was taken from groundwater, and the remaining 43+% (5,921) was taken from surface water (Figure 3). Fresh water use for gas production is projected to increase substantially from 2005 through 2007. The balance between groundwater and surface water use is projected to reverse in 2007, with an estimated 59% to be taken from surface water sources, and the remainder of 41% to be taken from groundwater (Table 2, Figure 4).

⁶ The manner in which companies reported drill rig counts differed from company to company. The number thus shown is an estimate, interpolated from the survey data.

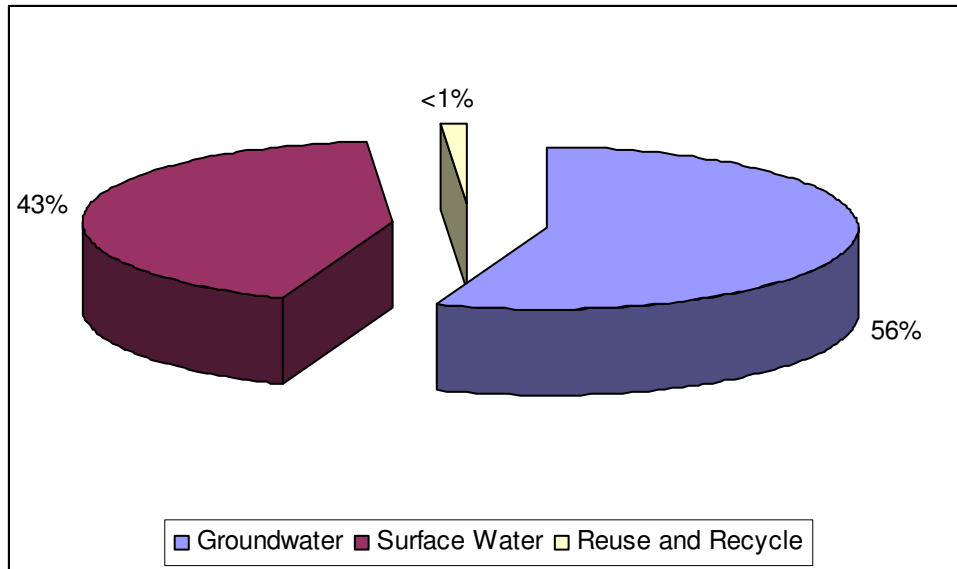


Figure 3 – Sources of fresh water for Barnett drilling and completion activities in 2006.

Table 2 – Estimates of freshwater use by Barnett gas producers extrapolated to the total Barnett play (includes the 20+/- % of drilling activity not encompassed by the survey).

| | 2005 | 2006 | 2007 |
|----------------------------------------|--------------|--------------|--------------|
| Groundwater used (ac-ft) | 3,785 | 7,688 | 6,615 |
| Surface Water used (ac-ft) | 4,245 | 5,921 | 9,647 |
| Total Fresh Water used (ac-ft) | 8,030 | 13,608 | 16,262 |
| % of Water Use as Groundwater | 47 % | 56 % | 41 % |
| % of Water Use as Surface Water | 53 % | 43+ % | 59 % |

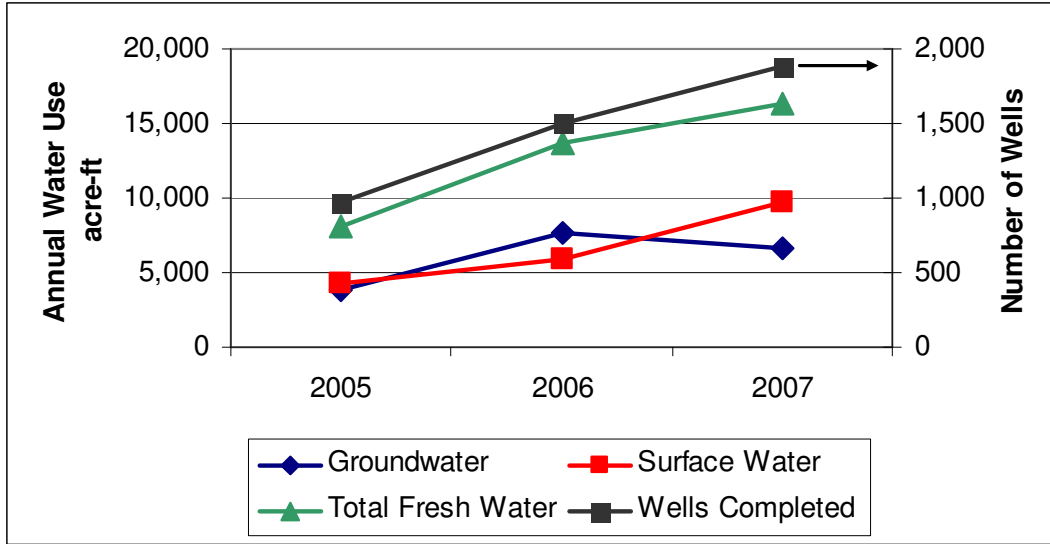


Figure 4 – Estimated fresh water use by Barnett gas producers by source, extrapolated from the GTI survey to the entire Barnett shale play.

Approximately 90% of fresh water use for Barnett gas well operations is for well completion (fracturing the formation) versus about 10% to actually drill the well bore; (see Figure 5, below).

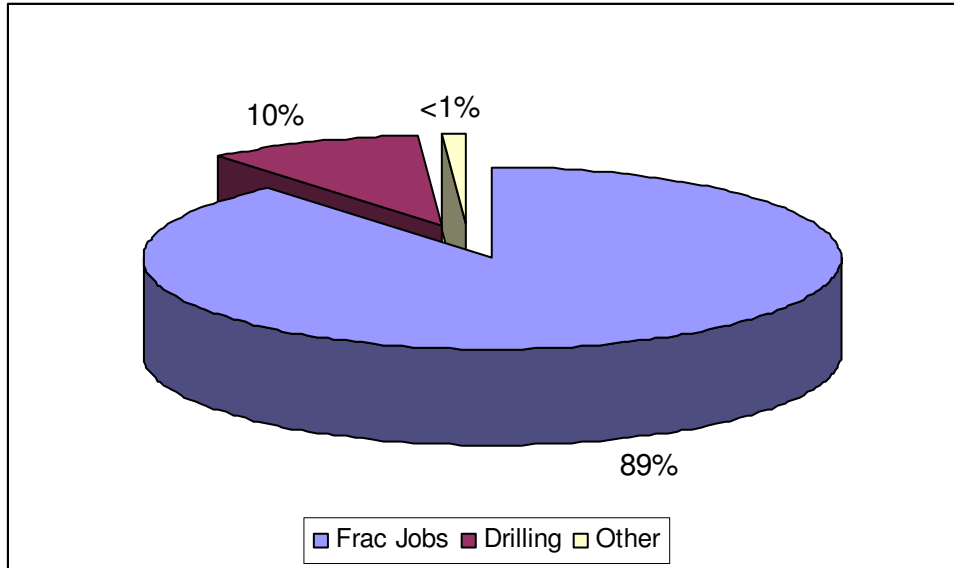


Figure 5 – Breakdown of fresh water use in drilling and completing a typical Barnett gas well.

Allocation of Freshwater Resources among Major Users

Data taken from Bene et al. (2007) indicates that total demand for freshwater (surface water and groundwater) for all users across the Barnett play in 2005 was about 1.5 million acre-feet, and that gas operators used about 0.5% of this. In 2010, the year in which BEG predicts that Barnett drilling activity is expected to peak, Bene et al. (2007) projects total freshwater demand by all users across the Barnett play to rise to approximately 1.7 million acre-feet, with gas operators using an estimated 1.7% of the total. These statistics are summarized in Figure 6 and Table 3 below⁷.

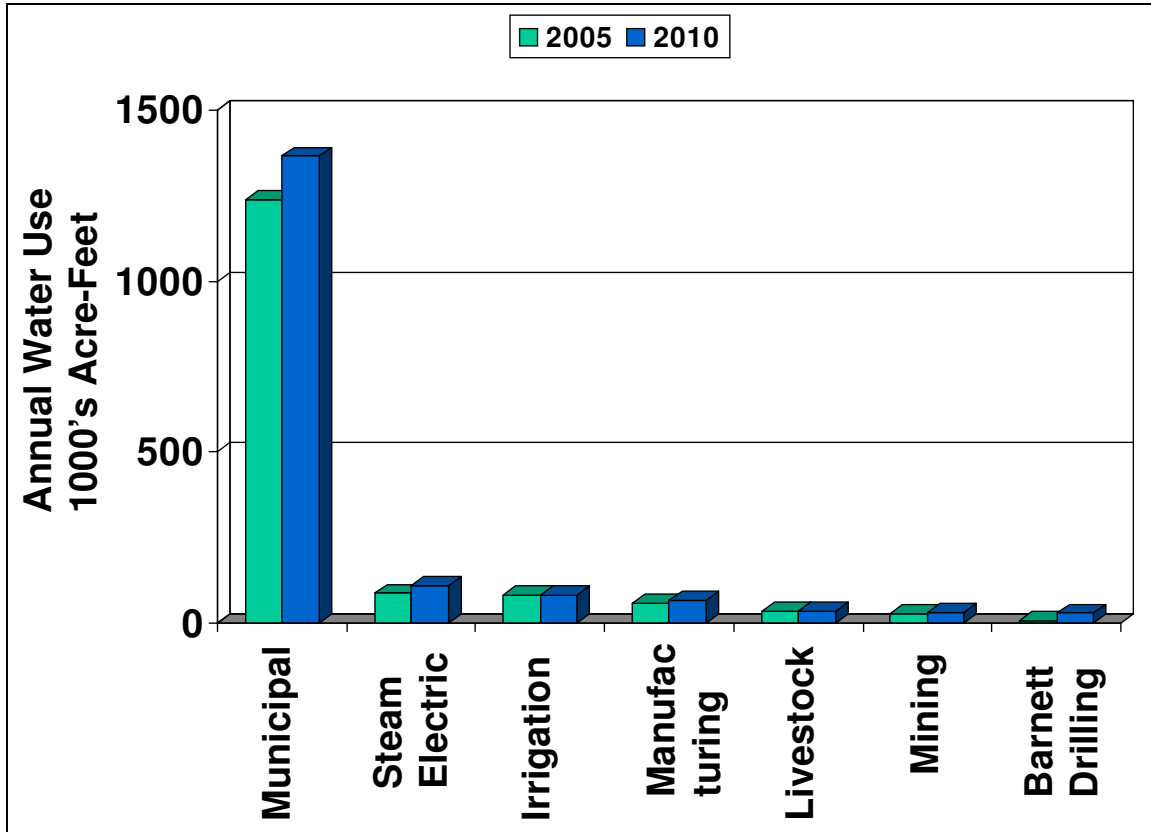


Figure 6 – Recent (2005) and projected (2010) total freshwater use in the Fort Worth Basin by user category.

Two things are obvious from these data: 1) Water use required for the development of the Barnett play was smaller than for any other water user in the Fort Worth Basin in 2005, and will remain so during the year of projected peak drilling activity, 2010; 2) Municipal water demand is clearly the predominant driver of the projected increase in total freshwater use from 2005 to 2010.

⁷ Barnett gas development water use statistics taken from TWDB's "high drilling activity" scenario: TWDB, 2007. Water use statistics for other users taken from Texas Water Development Board. 2006 Regional Water Plan: County Water Demand Projections for 2000 – 2060 .

It should further be noted that the projections of fresh water use presented here for 2010 represent the “high demand” scenario for Barnett drilling activity, prepared by BEG.

Table 3 – Recent (2005) and projected (2010) total freshwater use in the Fort Worth Basin by user category.

| FTW Basin Total Freshwater Use: 2005 | | | |
|---------------------------------------------|-----------|------------|---------------|
| Category | ac-ft | % of total | 1,000's ac-ft |
| Municipal | 1,238,732 | 80.4% | 1,239 |
| Steam electric | 87,945 | 5.7% | 88 |
| Irrigation | 82,730 | 5.4% | 83 |
| Manufacturing | 59,794 | 3.9% | 60 |
| Livestock | 36,093 | 2.3% | 36 |
| Mining | 27,385 | 1.8% | 27 |
| Barnett operations | 7,204 | 0.5% | 7 |

| FTW Basin Total Freshwater Use: 2010 | | | |
|---------------------------------------------|-----------|------------|---------------|
| Category | ac-ft | % of total | 1,000's ac-ft |
| Municipal | 1,364,810 | 79.4% | 1,365 |
| Steam electric | 108,942 | 6.3% | 109 |
| Irrigation | 82,782 | 4.8% | 83 |
| Manufacturing | 66,197 | 3.9% | 66 |
| Livestock | 36,335 | 2.1% | 36 |
| Mining | 30,484 | 1.8% | 30 |
| Barnett operations | 29,167 | 1.7% | 29 |

The proportional amounts of fresh water consumed by the natural gas industry compared to total demands in the Barnett play is shown in the following charts for the years 2005 and 2010 (projected). These comparisons are made for allocations of total freshwater, surface water and groundwater in Figures 7, 8 and 9, respectively.

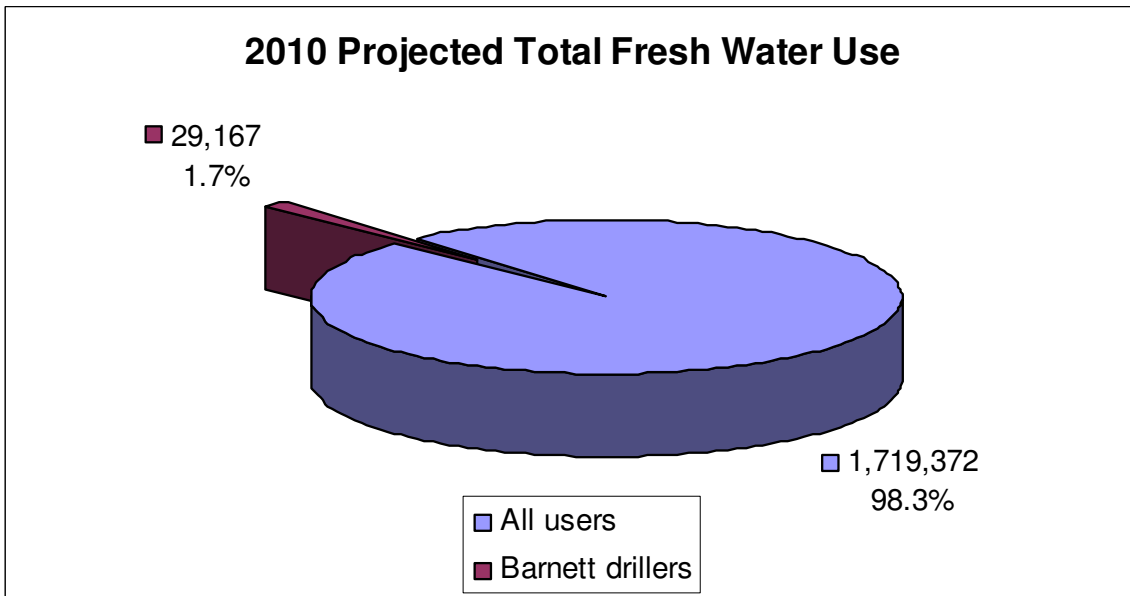
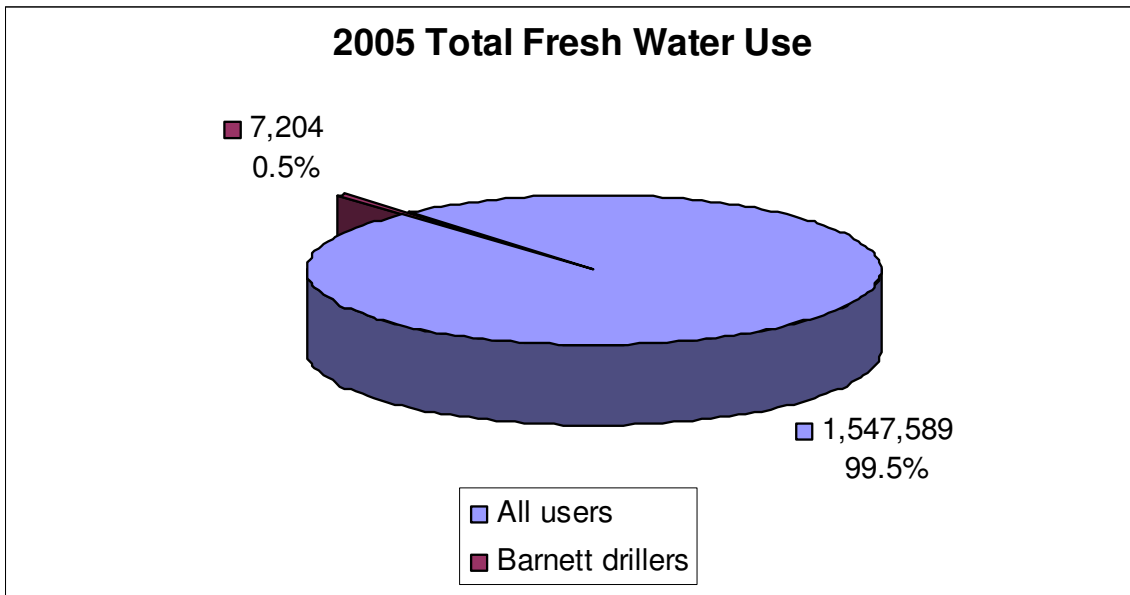


Figure 7a (above) and 7b (below) – Actual (2005) and projected (2010) total freshwater use in the Fort Worth Basin. Numbers given are acre-feet and relative per cent of the totals, under the “high use” (at peak drilling activity) projection by Bene et al. (2007). Note that the year 2010 is projected to represent the peak drilling year in the Barnett play.

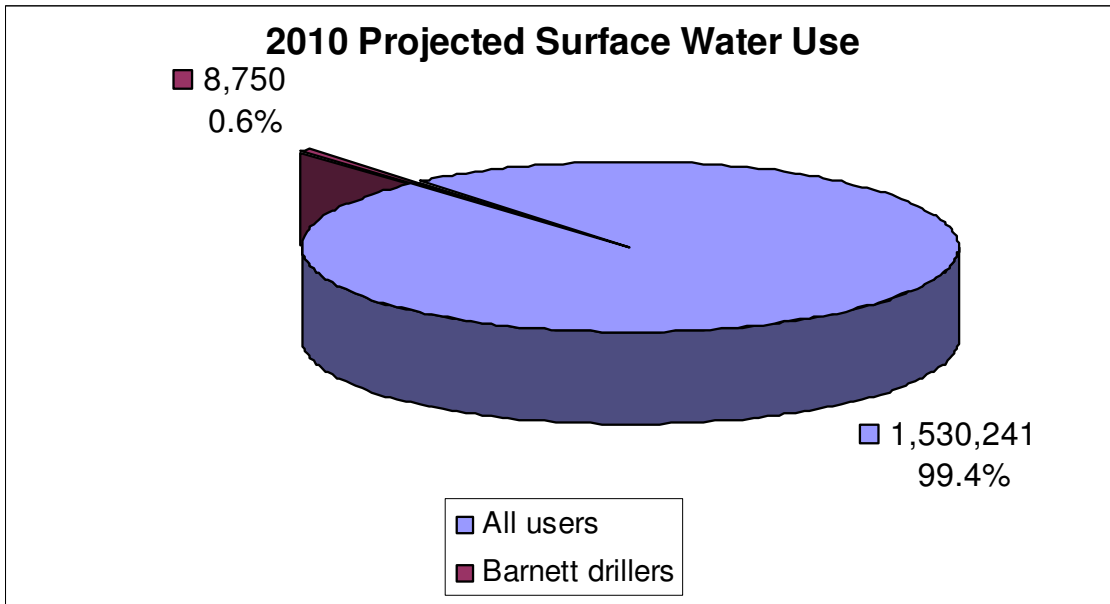
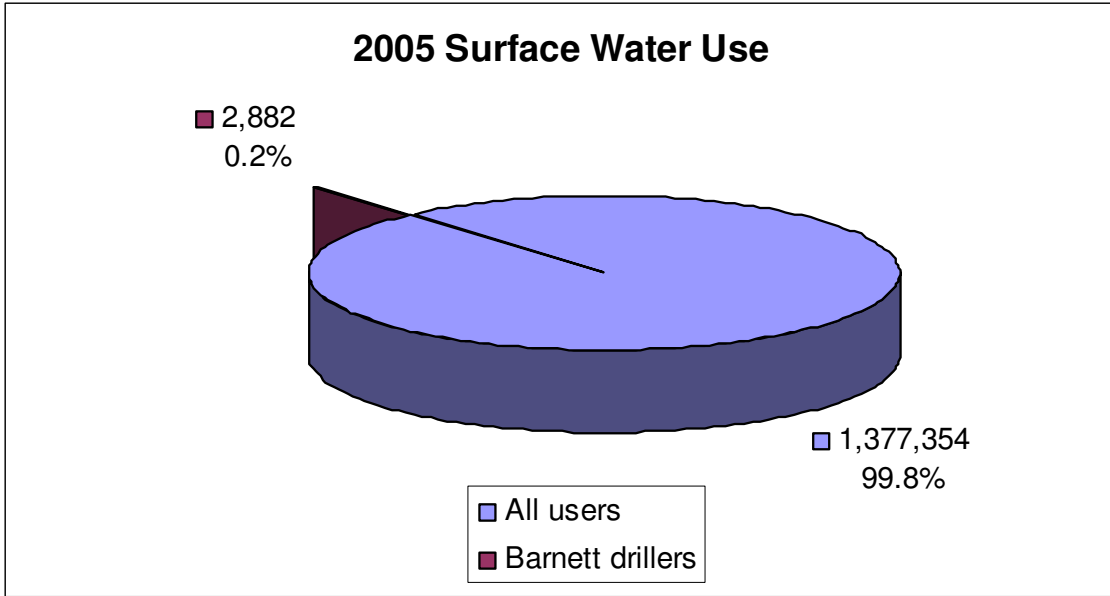


Figure 8a (above) and 8b (below) – Actual (2005) and projected (2010) surface water use in the Fort Worth Basin. Numbers given are acre-feet and relative per cent of the totals, under the “high use” (at peak drilling activity) projection by Bene et al. (2007). Note that the year 2010 is projected to represent the peak drilling year in the Barnett play.

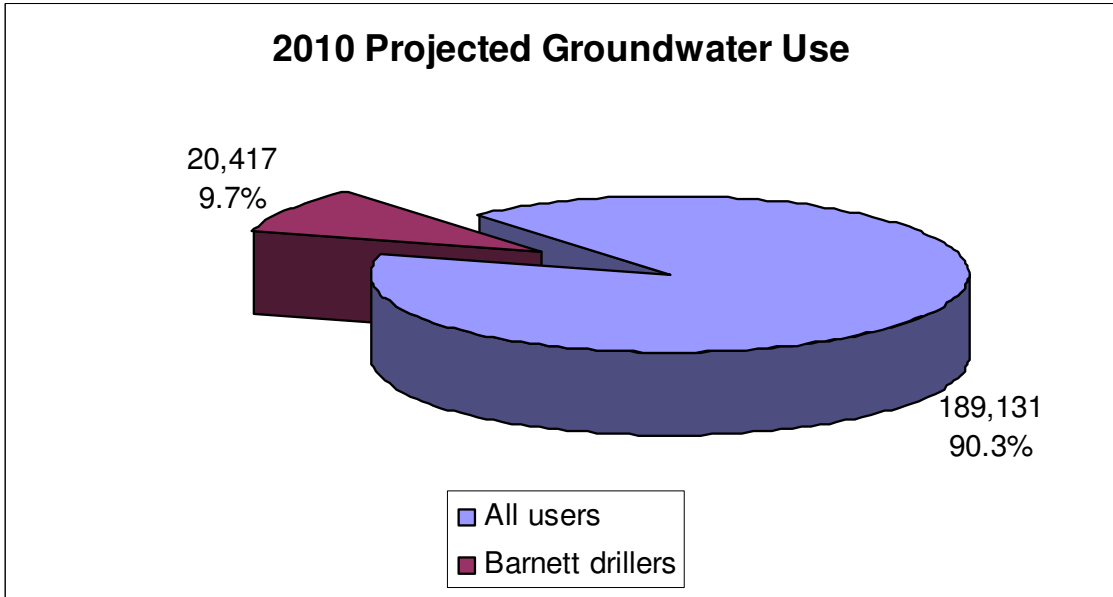
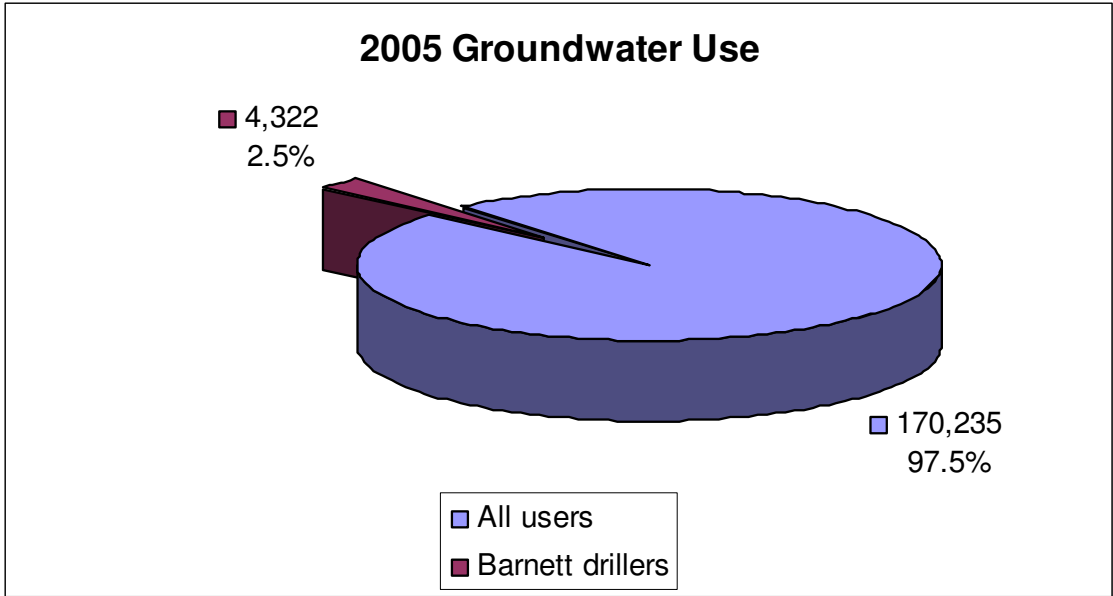


Figure 9a (above) and 9b (below) – Actual (2005) and projected (2010) groundwater use in the Fort Worth Basin. Numbers given are acre-feet and relative per cent of the totals, under the “high use” (at peak drilling activity) projection by Bene et al. (2007). Note that the year 2010 is projected to represent the peak drilling year in the Barnett play.

Bene et al. (2007) indicate that the incremental, projected increase in groundwater demand due to Barnett drilling (under BEG’s “high drilling activity scenario”) is believed to be “supportable in the regional sense”. That is, averaged across the Trinity/Woodbine aquifer system (the primary source of potable groundwater across the region), the projected levels of groundwater use are believed to be supportable through the period of the study (year 2025). Their report does indicate the potential for localized effects of increased aquifer drawdown and near the western margins of the Trinity aquifer.

Bene et al. (2007) projects that the expansion of Barnett drilling toward the more western margin of the play will result in demonstrable net increase in total groundwater use for these areas. Many counties are thus projected to see substantial increase in annual groundwater withdrawals during the years of high Barnett drilling activity. The fraction of groundwater taken by gas operators in some counties will correspondingly rise from a negligible amount in 2000-2005 to as much as 20 to 50 per cent or more of total groundwater withdrawals as drilling activity peaks in each county; (see Table 4, below).

Table 4 – Bene et al. (2007) county-specific projections of fractional groundwater withdrawals for Barnett shale gas development under their “high” drilling activity scenario⁸.

| County | 2005 | 2010 | 2015 | 2020 | 2025 |
|---------------|-------------|-------------|-------------|-------------|-------------|
| Bosque | 0% | 4% | 36% | 51% | 41% |
| Comanche | 0% | 0% | 1% | 3% | 2% |
| Cooke | 0% | 0% | 1% | 3% | 2% |
| Coryell | 0% | 0% | 4% | 38% | 60% |
| Dallas | 0% | 0% | 4% | 3% | 3% |
| Denton | 6% | 10% | 3% | 2% | 3% |
| Ellis | 0% | 0% | 2% | 1% | 1% |
| Erath | 0% | 3% | 19% | 11% | 12% |
| Hamilton | 0% | 3% | 29% | 66% | 52% |
| Hill | 0% | 8% | 40% | 27% | 29% |
| Hood | 0% | 11% | 18% | 8% | 11% |
| Jack | 0% | 6% | 27% | 14% | 17% |
| Johnson | 2% | 20% | 12% | 8% | 10% |
| McLennan | 0% | 0% | 1% | 6% | 5% |
| Montague | 1% | 1% | 7% | 34% | 35% |
| Palo Pinto | 0% | 0% | 1% | 4% | 2% |
| Parker | 1% | 26% | 21% | 10% | 13% |
| Somervell | 0% | 26% | 40% | 21% | 28% |
| Tarrant | 1% | 7% | 3% | 3% | 4% |
| Wise | 8% | 25% | 18% | 12% | 15% |

⁸ TWDB, 2002; Table 5b, page 20.

It is important to note that increased demand on groundwater in rural counties (e.g. Bosque, Coryell, Erath, Hamilton, Hill, Jack, Johnson, Montaque, and Somervell) does not necessarily indicate cause for alarm *where sufficient groundwater supplies are available*. In these counties, projected increases to double-digit percentage levels of groundwater use for gas drilling are mostly due to low human population and moderate economic activity. Nevertheless, it is important to note that the Trinity aquifer thins out toward the western part of the basin, indicating that there will be less groundwater available for extraction.

In localized areas of certain counties where well yields are limiting, projected increases in the proportional groundwater demand for natural gas drilling and completion indicate the need for due diligence and pro-active water resource planning. As a rule, the yield (flow rate) of individual water wells is generally correlated with the in-place groundwater supply; therefore, marginal areas of the Trinity aquifer will generally only support limited groundwater extraction rates. Where water well yields are below a certain threshold (50 gallons per minute), these areas will likely not have the groundwater supplies necessary to support substantial natural gas development; thus, gas operators will of necessity look to other sources.

Mitigation of Fresh Water Use through Improved Water Use Technology

On the Re-use of (High TDS) Flow-back Water

Approximately 9 acre-ft of fresh water is used in the drilling and completion of a typical horizontal gas well in the Barnett play. Most of this water returns as “flow back” during the first 30 to 90 days of production, with the remainder coming out and mingling with the native “produced” water of the Barnett formation over time. This flow-back water is highly mineralized (high in total dissolved solids, or “TDS”). The present practice of operators is to capture the “flow-back” water into “frac tanks” and truck it to various centralized facilities for down-hole disposal in deep formations.

Unfortunately, Barnett flow-back water is generally not recycled for beneficial use, such as subsequent well completions, for two reasons: 1) Well completion engineers have found that water high in total dissolved solids (TDS) causes down-hole and formation scaling and other problems; and, 2) The environmentally safe handling of high TDS waters is problematic over concerns of soil and potable groundwater contamination. If economical water management alternatives can be developed to remove constituents of concern and to recover demineralized water streams for purposes of recycling and reuse, significant reductions in freshwater use may be achievable for natural gas operations in the Barnett shale. Research is presently underway by some companies, as discussed below, to evaluate the feasibility of treating and recycling a significant portion of flow-back waters.

Recovery, Treatment and Recycling of Flow-back Water

Devon Energy and Fountain Quail Water Management are currently cooperating in a joint pilot project to de-mineralize Barnett flow-back water using micro-distillation at a site in Johnson County. The objective of this pilot project is to evaluate the feasibility of treating and recycling flow-back water for re-use by natural gas operators. An overview and summary of this project can be found at the Texas Railroad Commission's website⁹. Encana and Triad Rovon Services L.P. (TRS) are also cooperating in a joint pilot project to de-mineralize flow-back water using micro-filtration and reverse osmosis technologies¹⁰.

On the Use of Brackish and Saline Waters from Non-Potable Aquifers

A more difficult question to address relates to the viability of using water from non-potable aquifers to minimize the fresh water demands of Barnett operators. While the quantities of such waters are likely more than adequate, they are usually highly mineralized, containing total dissolved salts at concentrations that are not suitable for performing high quality frac jobs. The handling and use of such water for frac jobs may also require containment strategies to address environmental concerns. Therefore, it is unlikely that highly saline aquifers will be tapped in the near future for energy development in the Barnett play.

Alternate sources: switching from groundwater to surface water supplies

The fraction of water supplied to Barnett operators from surface supplies is projected to increase from 44% to 59% from 2006 to 2007. The corresponding change in the projected fraction of groundwater used thus drops from 56% to 41%. This demonstrates the considerable regional flexibility of Barnett operators to switch their source of fresh water based upon need, availability and location. Logistics and economics impose constraints on how much switching from groundwater to surface water supplies will ultimately be practicable in Barnett shale operations.

⁹ See: http://www.rrc.state.tx.us/divisions/og/wateruse_barnettshale.html.

¹⁰ Per personal communication with Douglas Mitchell of Encana.

Conclusions

The present and projected freshwater demands by Barnett gas producers are small relative to those of other users considered over the entire Barnett play. It is projected by Bene et al. (2007)¹¹ that Barnett operators will require less than 1% of surface water supplies and less than 10% of groundwater supplies in 2010, the year that BEG predicts Barnett drilling activity will peak. The relatively small proportional demand by Barnett operators on surface water supplies indicates no reason for concern. In contrast, the increase in the proportional take of groundwater by Barnett operators (from its present level of 2.5%) indicates that due diligence will need to be exercised by the industry as it develops groundwater resources, particularly in the more remote regions of the play where groundwater supplies are less abundant.

Barnett gas producers are presently active in evaluating improved technologies for reducing their net freshwater consumption. Pilot-scale research on flow-back water treatment and recycling presently is underway by Devon Energy, Encana and others to determine if some degree of flow-back water treatment and recycling may represent a technologically and economically viable means to reduce total freshwater use by Barnett shale gas operators.

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http://www.twdb.state.tx.us/data/popwaterdemand/2003Projections/Demand%20Projections/BoardApproved/County/county_demand_totals.htm

U.S. Geological Survey. 2004. Assessment of Undiscovered Oil and Gas Resources of the Bend Arch-Fort Worth Basin Province of North-Central Texas and Southwestern Oklahoma, 2003. USGS Fact Sheet 2004-3022. See:

<http://pubs.usgs.gov/fs/2004/3022/fs-2004-3022.pdf>

¹¹ ... based upon BEG's "high" Barnett drilling activity scenario.

Appendix A – Participating Companies

Barnett Shale Water Conservation and Management Committee: Member companies:

Chesapeake Energy
ConocoPhillips
Denbury Resources
Devon Energy
Encana Oil & Gas USA
EOG Resources
Harding Company
J-W Operating Company
Marathon Oil Company
Pitts Oil Company
Quicksilver Resources
Range Resources Company
Sauder Management Company
Shell Oil Company
Williams Production
XTO Energy

Companies providing data on their fresh water use:

Chesapeake Energy
Chief
ConocoPhillips
Denbury Resources
Devon Energy
Encana Oil & Gas USA
EOG Resources
Grand Energy
Harding Comp;any
J-W Operation Co.
Quicksilver Resources
Range Resources Company
Sauder Management Company
Shell Oil Company
Williams Production
XTO Energy

Appendix B - List of Counties in Study Area

Counties Encompassed in GTI Survey

Bosque
Denton
Erath
Hill
Hood
Johnson
Palo Pinto
Parker
Somervell
Tarrant
Wise

Additional Counties Encompassed in Bene et al. (2007)

Comanche
Cooke
Coryell
Dallas
Ellis
Hamilton
Jack
McClennan
Montague

Appendix C – Barnett Gas Producers Water Use by County

| County | Parameter | Year | | |
|--------|-------------------------------------|------|-------|-------|
| | | 2005 | 2006 | 2007 |
| Bosque | # Drill Rigs | | 1 | 1 |
| " | # Wells Drilled | | 14 | 12 |
| " | # Horizontal Wells Drilled | | 14 | 12 |
| " | # Vertical Wells Drilled | | 0 | 0 |
| " | Total Horizontal frac water (ac-ft) | | 56 | 48 |
| " | Total Vertical frac water (ac-ft) | | 0 | 0 |
| " | Total Groundwater used (ac-ft) | | 34 | 29 |
| " | Total Surface Water used (ac ft) | | 22 | 19 |
| Denton | # Drill Rigs | 11 | 9 | 11 |
| " | # Wells Drilled | 139 | 123 | 160 |
| " | # Horizontal Wells Drilled | 75 | 71 | 100 |
| " | # Vertical Wells Drilled | 64 | 52 | 61 |
| " | Total Horizontal frac water (ac-ft) | 783 | 752 | 1,060 |
| " | Total Vertical frac water (ac-ft) | 427 | 363 | 428 |
| " | Total Groundwater used (ac-ft) | 974 | 881 | 1,173 |
| " | Total Surface Water used (ac ft) | 236 | 234 | 315 |
| Erath | # Drill Rigs | 1 | 2 | 2 |
| " | # Wells Drilled | 13 | 19 | 27 |
| " | # Horizontal Wells Drilled | 13 | 19 | 27 |
| " | # Vertical Wells Drilled | 0 | 0 | 0 |
| " | Total Horizontal frac water (ac-ft) | 114 | 160 | 221 |
| " | Total Vertical frac water (ac-ft) | 0 | 0 | 0 |
| " | Total Groundwater used (ac-ft) | 68 | 94 | 127 |
| " | Total Surface Water used (ac ft) | 46 | 66 | 93 |
| Hill | # Drill Rigs | | 1 | 3 |
| " | # Wells Drilled | | 8 | 32 |
| " | # Horizontal Wells Drilled | | 8 | 32 |
| " | # Vertical Wells Drilled | | 0 | 0 |
| " | Total Horizontal frac water (ac-ft) | | 47 | 282 |
| " | Total Vertical frac water (ac-ft) | | 0 | 0 |
| " | Total Groundwater used (ac-ft) | | 24 | 196 |
| " | Total Surface Water used (ac ft) | | 23 | 86 |
| Hood | # Drill Rigs | 6 | 9 | 13 |
| " | # Wells Drilled | 67 | 117 | 158 |
| " | # Horizontal Wells Drilled | 67 | 117 | 158 |
| " | # Vertical Wells Drilled | 0 | 0 | 0 |
| " | Total Horizontal frac water (ac-ft) | 719 | 1,265 | 1,826 |
| " | Total Vertical frac water (ac-ft) | 0 | 0 | 0 |
| " | Total Groundwater used (ac-ft) | 155 | 357 | 452 |
| " | Total Surface Water used (ac ft) | 564 | 908 | 1,373 |

Appendix C (continued)

| County | Parameter | Year | | |
|------------|-------------------------------------|-------|-------|-------|
| | | 2005 | 2006 | 2007 |
| Johnson | # Drill Rigs | 12 | 36 | 26 |
| " | # Wells Drilled | 157 | 466 | 358 |
| " | # Horizontal Wells Drilled | 156 | 456 | 358 |
| " | # Vertical Wells Drilled | 1 | 10 | 0 |
| " | Total Horizontal frac water (ac-ft) | 1,610 | 4,436 | 2,811 |
| " | Total Vertical frac water (ac-ft) | 4 | 32 | 0 |
| " | Total Groundwater used (ac-ft) | 700 | 2,948 | 909 |
| " | Total Surface Water used (ac ft) | 914 | 1,520 | 1,902 |
| Palo Pinto | # Drill Rigs | | | 0 |
| " | # Wells Drilled | | | 8 |
| " | # Horizontal Wells Drilled | | | 5 |
| " | # Vertical Wells Drilled | | | 3 |
| " | Total Horizontal frac water (ac-ft) | | | 49 |
| " | Total Vertical frac water (ac-ft) | | | 0 |
| " | Total Groundwater used (ac-ft) | | | 44 |
| " | Total Surface Water used (ac ft) | | | 5 |
| Parker | # Drill Rigs | 4 | 7 | 10 |
| " | # Wells Drilled | 44 | 80 | 105 |
| " | # Horizontal Wells Drilled | 37 | 80 | 105 |
| " | # Vertical Wells Drilled | 7 | 0 | 0 |
| " | Total Horizontal frac water (ac-ft) | 340 | 788 | 1,070 |
| " | Total Vertical frac water (ac-ft) | 0 | 0 | 0 |
| " | Total Groundwater used (ac-ft) | 273 | 575 | 742 |
| " | Total Surface Water used (ac ft) | 67 | 213 | 329 |
| Somervell | # Drill Rigs | | 2 | 4 |
| " | # Wells Drilled | | 20 | 48 |
| " | # Horizontal Wells Drilled | | 19 | 48 |
| " | # Vertical Wells Drilled | | 1 | 0 |
| " | Total Horizontal frac water (ac-ft) | | 149 | 368 |
| " | Total Vertical frac water (ac-ft) | | 0 | 0 |
| " | Total Groundwater used (ac-ft) | | 82 | 184 |
| " | Total Surface Water used (ac ft) | | 67 | 184 |
| Tarrant | # Drill Rigs | 17 | 19 | 35 |
| " | # Wells Drilled | 225 | 262 | 499 |
| " | # Horizontal Wells Drilled | 219 | 262 | 499 |
| " | # Vertical Wells Drilled | 6 | 0 | 0 |
| " | Total Horizontal frac water (ac-ft) | 1,957 | 2,090 | 4,031 |
| " | Total Vertical frac water (ac-ft) | 19 | 0 | 0 |
| " | Total Groundwater used (ac-ft) | 499 | 548 | 784 |
| " | Total Surface Water used (ac ft) | 1,477 | 1,542 | 3,247 |

Appendix C (continued)

| County | Parameter | Year | | |
|--------|-------------------------------------|------|------|------|
| | | 2005 | 2006 | 2007 |
| Wise | # Drill Rigs | 5 | 7 | 7 |
| " | # Wells Drilled | 68 | 93 | 97 |
| " | # Horizontal Wells Drilled | 23 | 47 | 57 |
| " | # Vertical Wells Drilled | 45 | 46 | 40 |
| " | Total Horizontal frac water (ac-ft) | 252 | 508 | 621 |
| " | Total Vertical frac water (ac-ft) | 208 | 259 | 217 |
| " | Total Groundwater used (ac-ft) | 362 | 618 | 661 |
| " | Total Surface Water used (ac ft) | 98 | 149 | 177 |

Summary over All Counties

| Parameter | 2005 | 2006 | 2007 |
|-------------------------------------|-------|--------|--------|
| Total # Drill Rigs | 57 | 93 | 112 |
| Total # Wells Drilled | 713 | 1,202 | 1,504 |
| Total # Horizontal Wells Drilled | 590 | 1,093 | 1,401 |
| Total # Vertical Wells Drilled | 123 | 109 | 103 |
| Total Horizontal frac water (ac-ft) | 5,776 | 10,250 | 12,386 |
| Total Vertical frac water (ac-ft) | 659 | 655 | 645 |
| Total Groundwater used (ac-ft) | 3,033 | 6,160 | 5,301 |
| Total Surface Water used (ac ft) | 3,402 | 4,745 | 7,730 |