

**AN ANALYSIS OF UNCONVENTIONAL GAS WELL REPORTING
UNDER PENNSYLVANIA'S ACT 13 OF 2012**

Joel Gehman*

Alberta School of Business
University of Alberta

Diego Mastroianni

Desautels Faculty of Management
McGill University

Angela Grant

Faculty of Agricultural and Environmental Sciences
McGill University

Dror Etzion

Desautels Faculty of Management
McGill University

November 15, 2012

Forthcoming in *Environmental Practice*

* Corresponding author: 3-23 Business Building, Edmonton, AB T6G 2R6, Canada; (phone) +1-780-248-5855; (e-mail) jgehman@ualberta.ca.

**AN ANALYSIS OF UNCONVENTIONAL GAS WELL REPORTING
UNDER PENNSYLVANIA'S ACT 13 OF 2012**

ABSTRACT

In response to growing concerns about the impact of shale gas development, Pennsylvania's Act 13 of 2012 established an unconventional gas well fee and required the state's Department of Environmental Protection (DEP) to report on the number of such wells. In this article, we analyze the extent to which the DEP complied with its reporting requirements under Act 13. Using publicly available data, we find that the DEP likely omitted between 15,300 and 25,100 unconventional gas wells from its Act 13 report. Left uncorrected, we estimate that Pennsylvania's state, county, and municipal governments could forfeit fees of \$205–\$303 million in 2012 and up to \$0.75–\$1.85 billion cumulatively over the expected life of these wells. Rather than an isolated incident, evidence suggests that information management is a systemic and recurring problem within the DEP and its predecessor agencies. We propose the implementation of a relational database and geographic information system as a way for the DEP to fulfill its Act 13 obligations.

Unconventional shale gas grew from just 0.8% of natural gas production in the United States (US) in 1990 to 29.7% in 2011, according to the US Energy Information Administration (US EIA, 2012) and could account for 60% of production by 2035 (O’Keefe, 2012). As the pace and scale of unconventional shale gas development has accelerated, numerous environmental, health, and informational concerns have been raised (e.g., Cahoy, Gehman, and Lei, forthcoming; Colborn et al., 2011; Howarth, Santoro, and Ingraffea, 2011; McKenzie et al., 2012; Wyld and O’Neil, 2011). At the epicenter of these issues is the Marcellus Formation, where high-volume slickwater hydraulic fracturing has been used to extract natural gas from a 95,000-square-mile formation underlying six mideastern states (US EIA, 2011).

The recent Marcellus gas rush started in Pennsylvania, where 1,920 new unconventional wells were drilled in 2011, up from just 60 such wells in 2007 (Marcellus Center for Outreach and Research, 2012).¹ But even as drilling in Pennsylvania’s Marcellus Formation was booming, new questions about its potential impacts began emerging (e.g., Johnson et al., 2010; Osborn et al., 2011; Volz et al., 2011). As one response, Pennsylvania Governor Tom Corbett (2011) created the Marcellus Shale Advisory Commission (MSAC) and charged it with developing recommendations on all aspects of natural gas drilling. After holding 21 public meetings, hearing testimony from 60 experts, and reviewing more than 650 comments, the 30-member commission issued its final report in July 2011, comprised of nearly 100 policy recommendations (MSAC, 2011). Many of these recommendations were directly reflected in Act 13 of 2012, the most comprehensive revision of Pennsylvania’s oil and gas regulations since 1984 [Pennsylvania Department of Environmental Protection (PA DEP), 2012b; see also Rabe and Borick, 2012].

Enacted in February 2012, one significant component of Act 13 was the introduction of an unconventional gas well fee. To facilitate the assessment of these fees, Act 13 directed the

DEP to report on “all spud unconventional gas wells” in the state [58 Pa.C.S. §2304(a)]. In this article, we draw on three unique data sets derived from publicly available sources to analyze the extent to which the DEP has complied with its reporting requirements under Act 13. We find that the DEP’s Act 13 report likely omitted between 15,300 and 25,100 unconventional gas wells, which could be worth up to \$0.75–\$1.85 billion in fees over their initial life expectancy. We conclude with recommendations that would enable the DEP to meet its specific obligations under Act 13 while also better meeting the information needs of its diverse stakeholders more generally.

ACT 13 AND THE ASSESSMENT OF UNCONVENTIONAL GAS WELL FEES

Prior to the passage of Act 13, Pennsylvania was the only one of 28 major gas-producing states that did not impose a fee on natural gas drilling (Akin Gump, 2012; Fischetti, 2010; Rabe and Borick, 2012). Starting in 2012, however, unconventional gas wells were assessed \$190,000–\$355,000 in cumulative fees over 15 years if drilled horizontally and \$33,000–\$61,000 in cumulative fees over 10 years if drilled vertically.² In particular, Act 13’s *unconventional gas well fee* is based on four criteria: (a) well timing, (b) formation geology, (c) well purpose, and (d) unconventional spudding (i.e., drilling). Next, we review these criteria.

Criterion 1: Well Timing

First, fees are “imposed on every producer and shall apply to unconventional gas wells spud in this Commonwealth regardless of when spudding occurred” [58 Pa.C.S. §2302(b)]. By imposing fees retroactively, Act 13 implicitly required analysis of the more than 350,000 wells known to have been drilled in Pennsylvania dating to at least 1858 (Harper, 2008; PA DEP, 2011b).³ Act 13 considers all such wells to have been drilled in 2011 [58 Pa.C.S. §2302(b)].

Criterion 2: Formation Geology

Second, fee assessment depends on whether the well was spud in an *unconventional formation*, defined as “a geological shale formation existing below the base of the Elk Sandstone or its geologic equivalent stratigraphic interval” (58 Pa.C.S. §2301). The Elk Sandstone is a Late Devonian age formation. According to current subsurface nomenclature (Carter, 2007), at least 12 shale formations are below the Elk and thus meet Act 13’s definition of an unconventional formation (see Table 1).⁴

-- INSERT TABLE 1 ABOUT HERE --

Criterion 3: Well Purpose

Third, fee assessment depends on a well’s purpose. In particular, an *unconventional gas well* is “a bore hole drilled or being drilled for the purpose of or to be used for the production of natural gas from an unconventional formation” (58 Pa.C.S. §2301). By imposing this requirement, Act 13 implicitly exempts certain wells that would otherwise meet the above criteria. For instance, wells drilled for the purposes of injecting gas, petroleum, or another liquid related to oil or gas production or storage, including brine disposal, are exempt (58 Pa.C.S. §3203). Wells related to degasifying coal seams, and monitoring, producing, or extracting gas from solid waste disposal facilities, and wells drilled to produce potable water are also exempt. By comparison, all unconventional wildcat, developmental, and dry wells meet this criterion.

Criterion 4: Unconventional Spudding

Finally, fees depend on spudding, or “the actual start of drilling of an unconventional gas well” (58 Pa.C.S. §2301). In the oil and gas industry, spudding is distinct from activities such as completion and production, which can occur only after spudding, if at all. By anchoring the assessment of fees on spudding, Act 13 requires the identification of unconventional gas wells

without reference to completion or production. But, in that case, how does one differentiate unconventional and conventional wells, as both are essentially identical at the start of drilling? And how can the DEP retroactively determine whether an unconventional well has been spud if the necessary records were not kept? Next, we explore three possible answers to this question.

Spud interpretation 1: Permit issuance. Option 1 is to determine whether a well is unconventional at the time of permit issuance. Consistent with this interpretation, in April 2012, the DEP revised its well-permitting procedures to require any operator targeting an unconventional formation to apply for an unconventional gas well permit (PA DEP, 2012c). This revision would allow unconventional gas well fees to be assessed whenever a well permitted in an unconventional formation is spud, regardless of whether such a formation is ever reached or the well ever produces gas. However, this approach may not be retroactively feasible. For instance, until 1937, Pennsylvania did not require well operators to obtain permits before drilling.⁵ Even after this date, wells were frequently drilled without permits (Harper, 1982; Lytle, Heyman, and Wagner, 1967), and it was only with the passage of the Oil and Gas Act in 1984 that wells were required to be bonded. Until the passage of Act 13, operators routinely failed to notify the DEP of spudding, even though existing regulations required them to give the DEP 24 hours notice prior drilling (personal communication, 2012). Thus, in many situations, using this interpretation to determine the number of spud unconventional gas wells may not be possible owing to a lack of necessary historic data.

Spud interpretation 2: Drilling below the Elk. In the absence of reliable real-time permit and spud data on unconventional wells, a second option is to retrospectively differentiate between the start of surface drilling and the start of subsurface unconventional drilling. Although Act 13 does not explicitly make such a distinction, the DEP's interpretation of Act 13 appears to

do so: “An unconventional gas well is a well that is drilled into an unconventional formation, which is defined as a geologic shale formation below the base of the Elk Sandstone or its geologic equivalent” (PA DEP, 2012a). In other words, the DEP has interpreted Act 13 to mean that penetrating an unconventional formation below the Elk constitutes an unconventional gas well spud. This is noteworthy, because the Elk is surrounded by shale formations (Carter, 2007; Harper, 2008). Specifically, one or more unconventional shales (i.e., formations 1–3 in Table 1) exist throughout Pennsylvania’s oil and gas-producing regions. Accordingly, the population of wells liable for fees under spud interpretation 2 would minimally include all wells that penetrate the Tully Limestone, as there is no way to do so without first going through (i.e., spudding) an unconventional shale (see Figure 1). Additionally, wells spud in the three overlying shale formations would be liable for fees, whether or not they reached the Tully Limestone.

-- INSERT FIGURE 1 ABOUT HERE --

Spud interpretation 3: Targeted unconventional formation drilling. In cases where the data required for either of the foregoing options are unavailable, a third option is to consider wells as unconventional only when the specific formation targeted is unconventional. In other words, contrary to spud interpretation 2, spudding an unconventional shale formation en route to a deeper formation would not automatically result in unconventional well fees. Instead, only wells where the intended production formation contained shale would be liable for unconventional gas well fees. Because this interpretation is more stringent than Act 13 requires, it yields the most conservative estimate of impact fees. Nonetheless, it may be the only means of complying with Act 13 in some historic situations.

In sum, under Act 13, four criteria—well timing, formation geology, well purpose, and unconventional spudding—determine which wells are subject to unconventional gas fees. As a

practical matter, Act 13 considers wells drilled (a) anytime in Pennsylvania’s history, (b) to an unconventional formation (c) for the purpose of producing natural gas, (d) to be spud upon the commencement of drilling operations.

ANALYSIS AND FINDINGS

How many unconventional gas wells have been spud in Pennsylvania? To answer this question, Act 13 required the DEP to report all spud unconventional gas wells to the Pennsylvania Public Utility Commission (PUC) within 14 days of Act 13’s passage, along with updated reports on a monthly basis [58 Pa.C.S. §2301; 2304(a)]. Pursuant to this requirement, on March 1, 2012, the DEP posted an Act 13 report to its website, covering spud unconventional gas wells through December 31, 2011 (see PA DEP, 2012d). As shown in Table 2, the DEP reported 4,906 spud unconventional wells to the PUC. The vast majority—4,887 (99.6%)—were Marcellus wells spud from 2002 to 2011; the remaining 19 (0.4%) wells were spud since 2008 in other unconventional formations (e.g., Burket, Utica).

-- INSERT TABLE 2 ABOUT HERE --

Phase 1: The DEP Omitted 1,500 “Recent” Unconventional Spuds

The first phase of our analysis started with the DEP’s Act 13 report and focused on determining the extent to which the DEP accurately reported on *recent* unconventional well spuds—those between 2002 and 2011, as this was the time period explicitly covered by its report. In particular, we compared the DEP’s Act 13 report with its previously published reports covering the same period. Essentially, we used the DEP’s existing reports to assess the accuracy and completeness of its Act 13 report. This entailed downloading five additional DEP reports—permits, spuds, production, wastes, and compliance—all of which were publicly available on the DEP’s Office of Oil and Gas Management website. We combined these data with the DEP’s Act 13 report to form a single Structured Query Language (SQL) database. Within this database, we

used American Petroleum Institute (API) well numbers as unique identifiers, enabling us to construct a master table of unconventional wells. We considered a well to be *unconventional* if it was coded as a Marcellus (unconventional) well or a horizontal well in any of the six DEP tables.⁶ We identified which of these wells had been spud by evaluating the following criteria in stepwise order:

1. Was the well in the DEP's Act 13 table?
2. Was the well in the DEP's spuds table?
3. Was the well coded in the DEP's production table as producing gas or with a comment indicating it had been spud?⁷
4. Was the well coded in the DEP's wastes table as having produced waste?⁸
5. Was the well flagged in the DEP's compliance table as drilling commenced or drilling completed?⁹

At each step, we flagged as spud any wells in our master table that met one of these criteria but that were not previously identified as spud. These procedures resulted in the identification of 6,430 spud unconventional wells. The original DEP reports along with our SQL code and resulting tables are available for download in the Online Supplement accompanying this article.

Once this table was assembled, it was a simple matter to compare it against the DEP's Act 13 report. Upon doing so, we found considerable discrepancies. Specifically, we found that for the period 2002–11, a total of 1,524 spud unconventional gas wells were omitted from the DEP's Act 13 report. As shown in Table 3, this included 386 spud wells from the DEP's spuds table not included in its Act 13 report, another 934 spud wells from its production table, 120 spud wells from its wastes table, and 84 spud wells from its compliance table. Of these omitted wells, 1,330 wells (87.3%) were coded by the DEP as horizontal, whereas the rest were vertical.

The areal distribution of these omitted spuds is shown in Figure 2. As one check on validity of this estimate, we compared our results with those obtained using data assembled and distributed by the Carnegie Museum of Natural History (2012). Despite using a different vintage of data and following different procedures, it reported 6,503 unconventional wells as permitted, drilled, or producing through the end of 2011, a total within approximately 1% of our estimate.

-- INSERT TABLE 3 AND FIGURE 2 ABOUT HERE --

Phase 2: The DEP Omitted 13,800 to 23,600 “Early” Unconventional Spuds

The second phase of our analysis picks up where the DEP’s Act 13 report leaves off. Specifically, we sought to ascertain whether the lack of reported *early* unconventional gas wells spud prior to 2002 was also due to DEP omissions or whether in fact no such wells had been spud in Pennsylvania before 2002. We first searched scholarly databases for narrative histories of natural gas development in Pennsylvania, especially unconventional formations below the Elk Sandstone. This bottom-up analysis revealed numerous examples of unconventional gas well spuds prior to 2002. For instance, we uncovered several hundred early examples of gas wells spud in the Rhinestreet Shale (Kirr et al., 1986), the Marcellus Formation (Patchen et al., 1984), and the Cabot Head Shale (Harper and Cozart, 1988), among others, all of which are unconventional formations under Act 13. Given this evidence, we shifted our attention to a top-down assessment of possible missing records for these earlier years. Ultimately, we were able to assemble two different data sets, which together provide partial coverage of this earlier period.

We used data from the Pennsylvania Bureau of Topographic and Geological Survey (hereafter, Bureau). Created in 1919, the Bureau became part of the Pennsylvania Department of Conservation and Natural Resources (DCNR) in 1995, where it still performs many of the functions for which it was originally responsible. However, its oil and gas management responsibili-

ties were transferred to the DEP when that agency was created in 1995. Prior to this governmental reorganization, from 1950 to 1993, the Bureau published a series of Bulletins and Progress Reports that provide information on oil and gas well development in Pennsylvania through the end of 1991.¹⁰ In these publications, the Bureau categorized wells that penetrated the top of the Tully Limestone or its equivalent as *deep* on a stratigraphic basis, regardless of their actual vertical depth. Expressed in terms of Act 13, the Bureau's deep wells correspond with formations 4–12 in Table 1. As noted earlier, because there is no way to reach the Tully Limestone without spudding an unconventional formation, every deep well ever drilled qualifies as a spud unconventional gas well under spud interpretation 2.

Accordingly, we tabulated the drilling records published in the Bureau's reports.¹¹ The earliest reported deep well was drilled in 1888 and the last Progress Report issued by the Bureau covered deep wells completed through 1991. Overall, the Bureau reported that, through 1991, a cumulative total of 9,759 deep wells were completed in Pennsylvania. A spreadsheet of these data is available in the Online Supplement accompanying our article. Moreover, according to the Bureau, significantly more unconventional wells were likely spud during this period. For instance, in 1967 the Bureau wrote, "The total represents only the wells reported. A considerable number of completed wells were not reported" (Lytle et al., 1967, p. 5). Underreporting was apparently a long-standing problem. "In 1981 Pennsylvania oil and gas well drillers reported 3,554 well completions. . . . As in previous years, the number of wells reported was probably half the number actually drilled (an estimated 7,000 to 8,000 wells)" (Harper, 1982, p. 12; see also Patchen et al., 1981). Thus, according to the Bureau's own commentaries, through 1991 on the order of 19,600 or more unconventional gas wells were likely spud in formations 4–12.

Whereas the Bureau's reports provided aggregate data on selected deep wells, the Appalachian Basin Tight Gas Reservoirs Project (AB Project) compiled well-level data related to six specific formations in Pennsylvania and West Virginia (Behling et al., 2008). Funded largely by the US Department of Energy, the Bureau was a primary contractor on the AB Project. We obtained the database of Pennsylvania wells from the AB Project and based our analysis on 10,906 wells completed in the Medina Group during the period 1901–2007.

The Medina is composed of “sandstones, siltstones and shales” and “requires hydraulic fracturing in order to achieve commercial production” (Kimmel and Fulton, 1983, p. 1). Specifically, as shown in Table 1, the Medina includes the Cabot Head Shale, an unconventional formation under Act 13 (Carter, 2007).¹² Because the AB Project's data were largely derived from (and thus potentially overlap with) the Bureau of Topographic and Geological Survey's records, we only used data from 1992 onward, the year after the Bureau's reporting ended. Using this cutoff left 4,038 Medina wells completed between 1992 and early 2007. Using spud interpretation 3, each of these wells owes fees under Act 13.

Summary of Findings

Taken together, our analyses suggest that the DEP's Act 13 report minimally omitted some 15,300 unconventional gas well spuds.¹³ This total includes over 1,500 recently spud Marcellus wells, nearly 9,800 deep wells spud through 1991 (including Medina wells spud during this period), and over 4,000 Medina wells spud from 1992 through early 2007. As shown in Table 4, these wells have been drilled throughout Pennsylvania. Of note, we were able to identify each of these wells by name, number, and location.

-- INSERT TABLE 4 ABOUT HERE --

Additionally, our analysis suggests that the actual number of spud wells probably includes as many as 25,100 unconventional gas wells—all the above wells, plus an additional 9,800 deep wells considered “missing” from the Bureau’s records. Moreover, as described in the “Limitations” section below, our analysis covers only 962 (52%) of the 1,848 formation-years during which unconventional wells were potentially spud in Pennsylvania, suggesting that the number of unconventional wells omitted from the DEP’s Act 13 report could be significantly higher. Although we recognize that significant efforts may be required to identify the names, numbers, and locations of these latter wells, at no point do these circumstances relieve the DEP of its reporting requirements under Act 13.

Estimated Financial Consequences of the DEP’s Omissions

So far, we have focused primarily on fee assessment, but Act 13 also specifies requirements for the duration and collection of fees. Under Act 13, it is the DEP’s responsibility to report spud unconventional wells to the PUC, whereas the PUC is responsible for fee collection. Specifically, Act 13 grants the PUC “authority to make all inquiries and determinations necessary to calculate and collect the fee, administrative charges or assessments imposed under this chapter, including, if applicable, interest and penalties” (58 Pa.C.S. §2307). But, in the absence of accurate information from the DEP, the PUC cannot collect these fees. What revenue shortfalls could result from the DEP’s omissions?

According to Act 13, fees are due for 15 years in the case of horizontal wells and 10 years in the case of vertical wells [58 Pa.C.S. §2302(b)]. Additionally, if after 10 years a well is restimulated, fees are due for another 15 or 10 years, respectively [58 Pa.C.S. §2302(d)]. Once a well is spud, there are only two ways for a well operator to avoid liability for these fees: nonproduction and plugging. If within two years after paying the initial fee a spud unconventional well

is incapable of producing more than 90,000 cubic feet of gas per day during any month, then the fee shall be suspended [58 Pa.C.S. §2302(b.1)]. In this case, fees are due for a minimum of three calendar years (PA PUC, 2012a). After spudding, an operator may also certify that a well has ceased production and has been plugged according to regulations established by the DEP [58 Pa.C.S. §2302(e); 3220], at which point fees would cease in the year following plugging certification. Of note, at no point does Act 13 exempt so-called inactive wells from fees (58 Pa.C.S. §3214). Stated plainly, the wells subject to fees are spud wells, unconventional wells, vertical wells, capped wells, and restimulated wells (PA PUC, 2012b, p. 3).

All wells spud prior to 2012 are considered spud in 2011 and owe fees of \$50,000 and \$10,000, respectively, depending on whether they are horizontal or vertical (58 Pa.C.S. §2302; PA PUC, 2012b, p. 5). We have documented over 1,300 omitted spud horizontal Marcellus wells, which collectively owe \$65 million in unconventional gas well fees. Another 14,000 omitted Marcellus, deep, and Medina wells (assumed to be vertical) owe \$140 million in fees.¹⁴ Left uncorrected, these omissions represent at least \$205 million in lost revenues in 2012 (see Table 5). Of note, these fees are distinct from and additional to the \$211 million in fees that have been estimated based on the DEP's Act 13 report (Detrow, 2012c). In other words, if properly implemented, Act 13 will provide state, county, and municipal governments with nearly twice the 2012 revenue previously estimated.¹⁵

-- INSERT TABLE 5 ABOUT HERE --

Unless these wells are certified as plugged, the fees are due for a minimum of three calendar years (58 Pa.C.S. §2302; PA PUC, 2012a), implying a \$431–\$636 million omission by the DEP (see Table 5). Assuming well lives of 15 and 10 years for horizontal and vertical wells, respectively, the cumulative cost of the omissions could total \$0.75–\$1.27 billion over time. Addi-

tionally, our analyses suggest that the actual number of spud wells probably includes as many as 25,100 unconventional gas wells. Assuming these additional missing wells are all vertical, these omissions represent another \$98 million in unconventional gas well fees (see Table 5). In sum, owing to the DEP's omissions, the state, county, and municipal governments designated by Act 13 could forfeit fees of \$205–\$303 million in 2012, and unless these wells are plugged or incapable of sufficient production, up to \$0.75–\$1.85 billion over their expected lives.¹⁶

DISCUSSION

The emergence of environmental and sustainability concerns frequently generates demands for increased disclosure and reporting (Etzion and Ferraro, 2010; Gallagher and Song, 2011). In the case of the DEP, it appears that managing the disclosure and reporting required by Act 13 has resulted in potentially widespread and systemic omissions. Moving forward, if the DEP is to meet the requirements of Act 13, a more robust approach will be needed. As with unconventional gas drilling and exploration more generally, the problem implicates “three spatial dimensions and time” (Mooney, 2011, p. 82).

Surmounting Pennsylvania's Legacy of Oil and Gas Information Management Problems

Unfortunately, information management appears to be a long-standing problem within the DEP and its predecessor agencies. In 1980, the Bureau reported it was working on a two-year project to compile, standardize, and computerize 27,000 deep well records: “Determining the historical data has presented numerous problems. Some of the information has been lost with time, whereas other information is confused because different workers have used different names, dates and geographic localities” (Piotrowski, 1980, p. 35).¹⁷

Six years later, the Bureau reported that it had again “begun the process of computerizing its well record files” (Harper, 1986, p. 38), by then numbering more than 100,000 wells. In 1993, the Bureau launched a third “multiyear project to compile an electronic information system

based on all the oil and gas data on file in hardcopy format” (Cozart and Harper, 1993, p. 33). This project—the Wells Information System—continues to this day, though under the auspices of the DCNR and not the DEP as one might expect. Despite these multiple attempts at computerization over a 30-year period, the status of at least 184,000 wells in Pennsylvania remains “unknown” (PA DEP, 2000).

In addition to these documented issues, other data management problems appear to have gone largely undetected. In the process of analyzing the DEP’s wastes reports, we noticed there were only four records for all of 2007, compared with some 15,000 records in 2006 and 25,000 records in 2008. What happened in 2007? After asking the DEP for an explanation, we were told “we had a system crash and lost most of our 2007 waste reports” (personal communication, 2012), suggesting that the DEP had neglected to perform routine backups, a common data management practice. Others have documented numerous missing permit and spud records, as well as inconsistent Marcellus designations (Hamill, 2012; Whitacre and Wenzel, 2011).

Although our study did not attempt to identify the mechanisms that may be responsible for the DEP’s inability to build and maintain an accurate database of drilling activity, prior organizational research suggests several plausible explanations. Most sinister is the possibility of *regulatory capture* (Levine and Forrence, 1990), wherein governmental agencies succumb to narrow special interests, straying from the goal of serving their intended public constituencies. Another possibility is that the DEP exists in a state of *permanent failure* (Meyer and Zucker, 1989), wherein organizational members focus their attention and efforts primarily on organizational survival rather than organizational performance. A third possibility is that the DEP recognizes the need for improved organizational performance, yet is unable to implement a robust program of *organizational learning* (Argote, 1999; Argyris and Schön, 1978) that will enable it

to fundamentally address the root causes underlying its data management problems. The extent to which these mechanisms may be to blame is beyond the scope of our article, but may be fruitful possibilities for the DEP and future research to consider.

Some Options for Building a Robust Well Information System

Although dealing with multiple relational and temporal complexities such as these can be challenging (Garud and Gehman, 2012; Garud, Gehman, and Kumaraswamy, 2011), in the case of the DEP and Act 13, it appears that many of these challenges could be addressed by building a platform capable of bridging the legacies of the past and the needs of the future, while performing in the present. For instance, with a properly designed relational database (RDB) and geographic information system (GIS) (Belieu, Paque, and Simmers, 2001; Bonham-Carter, 1994; National Research Council, 2012), the analysis required by Act 13 would be rather straightforward.

A first step in building such a system would be for the DEP to develop a RDB containing permitted well locations, proposed drilling depths, and formations targeted, to name just a few variables. These attributes are all required by the DEP's *Permit to Drill or Alter an Oil and Gas Well* (PA DEP, 2012c). Once these data were at hand, it would be a simple matter to import the wells as geospatial data into an application such as ArcGIS. Then, together with spatial data representing the depth to geological formations, the proposed drilling depth could be used to determine whether wells will penetrate unconventional formations (Mamoulis, 2012). Wells where the depths of unconventional formations are less than the proposed drilling depths would be flagged as unconventional and reported to the PUC when spud, as required by Act 13.

In developing such a system, the DEP could leverage a number of existing standards. For instance, Federal Geographic Data Committee guidelines specify metadata standards relevant to

GIS (Behling et al., 2008). Similarly, the PPDM Association publishes database standards specifically designed to help the oil and gas industry manage well-related data (PPDM, 2012). PPDM 3.8, the latest version of its open standards data model, covers 53 subject areas, which include various standards related to wells, geology, environment, health, and safety data, among others. In sum, a RDB-GIS built on standards such as PPDM would allow the DEP to aggregate and manage the various data associated with each well in a more comprehensive manner, thereby enabling it to meet the requirements of Act 13.

Without an accurate diagnosis of the organizational issues underlying the DEP's data management difficulties, it is difficult for us to provide meaningful suggestions extending beyond this list of best practices. One arena, however, may help the DEP immensely, albeit indirectly: improved governance. Ostrom (1990) has shown that governance mechanisms that increase transparency and integrate data and preferences at multiple levels of a system are conducive to maintaining the long-run integrity of public resources (i.e., a commons). Relatedly, other research has shown that contentious, multi-stakeholder issues may be governed more effectively through hybrid forums (Callon, Lascoumes, and Barthe, 2009). Enhanced public access to data could serve not only to improve the quality and reliability of the DEP's information systems, but could lead to greater awareness of the extent of drilling in the state, as well as its positive and negative consequences. Unfortunately, rather than taking such a distributed approach to governance, Act 13 centralizes authority, "largely eviscerating the possibility of constructive engagement between state and local governments" (Rabe and Borick, 2012, p. 16).

Limitations

When interpreting our analysis and results, there are several limitations to keep in mind. First, owing to data limitations, we were unable to evaluate the number of spud wells in numer-

ous formations and years. As depicted in Figure 3, the extent of these limitations can be calculated as a grid of 12 formations multiplied by 154 years (1858–2011), or a total of 1,848 formation-years. Data from the Bureau enabled us to estimate spuds in nine formations from 1888 to 1991, or 936 formation-years. The AB Project provided spud estimates for a single formation—the Medina Group—over a 16-year period. Finally, data from the DEP enabled us to estimate Marcellus spuds from 2002 to 2011, or another 10 formation-years. In other words, the available data covered only 962 (52%) of the 1,848 formation-years during which unconventional wells were potentially spud in Pennsylvania. To the extent that additional unconventional gas wells were spud in the 886 formation-years for which no data were available, our estimates may significantly understate the true scope of the DEP’s omissions. For instance, in the mid-1980s, one operator reportedly completed more than 100 Rhinestreet Shale penetrations (Kirr et al., 1986), all of which are unconventional wells under Act 13, but none of which are included in our estimates, owing to a lack of relevant publicly available data.

-- INSERT FIGURE 3 ABOUT HERE --

Second, we were unable to independently verify the accuracy of the data we used. In short, our conclusions are only as good as the data we have used, and in all cases we have been essentially limited to data produced by the very agency we have endeavored to assess. However, these data have been shown to suffer numerous problems (e.g., Harper, 1982; Whitacre and Wenzel, 2011). As a result, our analysis may significantly underestimate the number of unconventional gas wells spud. Accordingly, the omitted spuds that we have documented may well be the lower bound of the true number of omissions by the DEP, were such data available.

Third, as one anonymous reviewer pointed out, it is possible to use more or less stringent criteria when determining whether a well was spud. Such choices would result in corresponding-

ly higher or lower estimates of the number of spud unconventional wells. For example, we determined the number of spud wells in part by using the DEP's production and wastes reports, but these reports are based on activities that take place after a well is completed. To the extent that other wells were spud in unconventional formations, but not yet completed (and thus not reported in the production or wastes tables), our count of spud unconventional wells may be artificially low. Accordingly, we made every effort to interpret the DEP's publicly available data sets appropriately. Because the DEP provides few descriptions, codebooks, or metadata for its reports, we consulted with the DEP to confirm our interpretation of its database codes on multiple occasions, hardly an ideal situation. Ultimately, the number of wells omitted by the DEP depends on interpretations of whether a given well meets the criteria required by Act 13, and such interpretations are themselves constrained by the quality of the underlying data.

Fourth, Act 13 suffers from several ambiguities. This is not entirely surprising, as laws are "inherently flexible" (Thornton, Ocasio, and Lounsbury, 2012, p. 12) and subject to changing interpretations (Edelman, Uggem, and Erlanger, 1999). Indeed, Act 13 confirms these observations. For instance, despite issuing a "final order" in May 2012 (PA PUC, 2012a), the PUC later revised its interpretation of vertical well fees (PA PUC, 2012c; see also note 14). Other aspects of Act 13 have been ruled unconstitutional and have been appealed to the Pennsylvania Supreme Court (Detrow, 2012a,b). In addition to legal disputes that are still unfolding, other potential ambiguities have yet to be considered. For instance, at no time does Act 13 define what qualifies as a *geologic shale formation*, leaving the meaning of this phrase open to interpretation. In this article, we interpreted the phrase quite narrowly, including only known organic rich shale lithofacies, meaning shales that constitute distinct stratigraphic intervals capable of producing hydrocarbons (Carter, 2007; Harper, 2008; Rushing, Newsham, and Blasingame, 2008). But Act 13

imposes no requirement that unconventional formations be rich in organic materials. This is potentially significant because throughout Pennsylvania the Elk Sandstone is immediately underlain by one of two formations (see Figure 1). The Brallier Formation is a “fine-grained, siliceous shale” (Butts, 1918). In areas where the Brallier is nonexistent, the Angola Shale is present. In other words, there is no way to penetrate below the Elk Sandstone without immediately spudding shale. However, we did not count wells spud into these two shales as unconventional wells and thus may have omitted a significant number of wells subject to Act 13.

Another definitional ambiguity relates to *hydraulic fracturing*, a phrase that Act 13 invokes several times but never defines. For instance, an *unconventional formation* is defined in part as an interval “where natural gas generally cannot be produced at economic flow rates or in economic volumes except by vertical or horizontal well bores stimulated by hydraulic fracture treatments or by using multilateral well bores or other techniques to expose more of the formation to the well bore” (58 Pa.C.S. §2301). But this mention proves to be a red herring, as Act 13 never conditions the assessment of fees on hydraulic fracturing, multilateral well bores, or other formation exposure techniques. Indeed, no such techniques need be performed for a well to be considered spud, as, by definition, such activities can occur only after spudding, if they ever occur at all. Collectively, the four types of limitations described above suggest that while our results provide ample evidence of reporting problems, our analysis should not be interpreted as a definitive or comprehensive assessment of these problems.

Conclusion

Unconventional shale gas development has become widespread, bringing with it a growing number of concerns. Critical to untangling these many controversies is better information. Twenty years ago, the Bureau wrote, “For 125 years oil and gas well drillers and producers have

had a veritable free hand in Pennsylvania” (Harper and Cozart, 1992, p. 38). Act 13 of 2012 is simply Pennsylvania’s latest effort to close this gap. Our analysis of the DEP’s Act 13 reporting suggests that, unfortunately, this “veritable free hand” persists.

Our intention in this article has not been to determine the exact number of unconventional gas well spuds in Pennsylvania, but to assess the extent to which the DEP has fulfilled its Act 13 reporting requirements. Though clearly more than 4,906 unconventional gas wells were spud by the end of 2011, determining the true number of such wells remains the DEP’s responsibility. In this regard, we hope that our analysis may prompt the DEP to reconsider its statutory requirements more carefully. Until these omissions are corrected, the many state, county, and municipal stakeholders impacted by unconventional gas well drilling will not be compensated for the impacts of unconventional gas wells as required by Act 13.

ACKNOWLEDGMENTS

This research was initiated while the first author was a doctoral candidate at the Smeal College of Business, Pennsylvania State University. The authors gratefully acknowledge the financial support of the Social Sciences and Humanities Research Council of Canada (SSHRC Award 410-2009-1259). We owe a special thank-you to John Wenzel and James Whitacre of the Powdermill Nature Reserve at the Carnegie Museum of Natural History for their helpful suggestions and encouragement during the article's development and revisions. We thank Mary Behling of the West Virginia Geological and Economic Survey for assistance related to the Appalachian Basin Tight Gas Reservoirs Project, an information technology specialist at the Pennsylvania Department of Environmental Protection for clarifying its oil and gas reports on several occasions, and an assistant counsel in the Department's Bureau of Regulatory Counsel for summarizing the regulatory basis of its well permitting authority. We thank the journal and special issue editors and two anonymous reviewers for their input on our original paper. Separate from *Environmental Practice's* review process, in May 2012 we offered both the Pennsylvania Department of Environmental Protection and the Pennsylvania Public Utility Commission an opportunity to review our findings, but neither agency offered any comments.

NOTES

1. Many assume the Marcellus Formation is a recent discovery, but "in reality, the Marcellus has been a known gas reservoir for more than 75 years" (Harper, 2008, p. 2).
2. Although a complete comparison of state oil and gas taxes is beyond the scope of our article, Kunce and Morgan (2005) compared severance, property and corporate taxes in eight major oil and gas-producing states from 1970 to 1997. More recently, Rabe and Borick (2012, p. 13) concluded that Act 13 imposes "an effective tax rate of between 1 and 2 percent during the initial years of fee operation," with marked declines in later years, a level "substantially below the effective tax rate of all other state oil and gas producers." By comparison, Texas imposes a 7.5% severance tax, representing some 10% of total state revenues (Kunce and Morgan, 2005; Rabe and Borick, 2012).
3. After the tremendous success of the gas well in nearby Fredonia, New York, numerous gas wells had been drilled along the shores of Lake Erie by 1858. Drake's famous oil well followed closely behind in 1859.
4. This nomenclature was not necessarily operant historically. For instance, the Medina Group (Carter, 2007) was known as the Albion Formation until as late as 1995 (Ryder, 2004). As a result, the analysis must also consider alternative designations for these same formations.
5. Passed in July 1937, P.L. 2772 required "certain records of oil and gas wells drilled in the Commonwealth showing the location of the same and the geologic formations encountered therein." This law was superseded by Act 359 of 1961, the Oil and Gas Conservation Law. According to the DEP (personal communication, 2012), its current authority to require well permits rests on Act 223 of 1984, the Oil and Gas Act (58 Pa.C.S. §3211).

6. We identified a total of 185 wells that were coded as horizontal in one or more of the DEP's reports, but not coded as Marcellus or unconventional in any of its reports. Upon encountering this potential anomaly, we sent a file containing all 185 wells to the DEP. After reviewing the file, a DEP information technology specialist confirmed that these wells were all unconventional, despite being omitted from its Act 13 report (personal communication, 2012).

7. The DEP's production report contains a "comment" field. For many wells, no comments were provided. In other instances, operators provided one of the following comments: (a) currently being drilled; (b) drilling finished, well not yet completed; (c) transferred this well; (d) plugged well; (e) regulatory inactive well; (f) well shut-in; (g) sold this well; and (h) abandoned well. According to the DEP (personal communication, 2012), any well containing one of these comments has been spud, as these activities are only possible after spudding.

8. According to the DEP (personal communication, 2012), the only way for a well to produce wastes is for it to have been spud. Indeed, until spudding no well exists to generate wastes.

9. From our master table of unconventional wells, we identified 432 unique wells associated with a total of 974 inspection records. Using a codebook provided by the DEP (personal communication, 2012), we manually reviewed all 974 records. We coded 133 inspections (13.7%) associated with 84 unique wells (19.4%) as spud.

10. Through 1966, the Bureau reported on wells completed during the preceding year. Starting in 1967, it reported on well completion records received, regardless of when drilled. See Progress Report 177 (Kelley et al., 1969).

11. Our analysis is based on Bulletins M31, M39, and M49, and Progress Reports for 1960–91.

12. An anonymous reviewer objected, agreeing that while the Medina Formation qualifies as an unconventional formation under the meaning of Act 13, such wells should not be considered liable for fees because the Cabot Head Shale is not highly productive. In its efforts to avoid imposing a severance tax, however, Act 13 imposed fees without regard to production (Rabe and Borick, 2012). Under 58 Pa.C.S. §2302, spudding is all that is required.

13. As one check on the credibility of this estimate, consider data available from TGS (2012), a provider of "geoscientific data products and services to the oil and gas industry." TGS has "identified over 270,000 wells within the Marcellus trend" and "over 18,500 wells with known Marcellus penetrations."

14. After our article was accepted for publication, the PUC reconsidered its treatment of vertical wells. For a discussion of the potential impact of this ruling on the estimated financial consequences of the DEP's omissions, please see the Addendum in the Online Supplement.

15. Act 13 uses a complex formula to allocate impact fees, with nearly 20 pages of legislative text required to outline the distribution among state, county, and municipal governments (58 Pa.C.S. §2313; see also PA PUC, 2012b; Rabe and Borick, 2012). For 2012, the first \$23 million in fees is earmarked for various state programs, such as the Pennsylvania Fish and Boat Com-

mission, the State Fire Commissioner, and the Natural Gas Energy Development Agency (58 Pa.C.S. §2313; see also PA PUC, 2012b). These off-the-top earmarks fluctuate based on inflation and other factors specified in Act 13. Of the remaining fees, 60% is allocated to counties and municipalities, again based on a rather involved calculus, and 40% is allocated to the Marcellus Legacy Fund. To be eligible to receive funds, Act 13 required counties to adopt uniform zoning laws prohibiting their ability to zone and regulate oil and gas drilling, and restricted how counties and municipalities could use the funds they receive. However, in a July 2012 ruling, Pennsylvania's Commonwealth Court voided 58 Pa.C.S. §3304; 3215(b)(4), ruling that Act 13's zoning restrictions "unconstitutionally bar local governments from their right to separate industrial activity from residential neighborhoods" (Detrow, 2012a). Seeking expedited review, attorneys representing the PUC and the DEP have since filed an appeal with the Pennsylvania Supreme Court. In the meantime, the rest of Act 13 remains in force.

16. Our estimates are based on data that provide only partial coverage of the formations and years over which unconventional wells were potentially spud. Here we can only speculate, but if the ratio of omitted wells is similar, these omissions could represent an additional \$250 million in 2012 fees.

17. Thirty years later, problems with inconsistent reporting persist (e.g., see PA DEP, 2011a).

REFERENCES

- Akin Gump. 2012. *Pennsylvania Passes Shale Gas Drilling Law*. Akin Gump Strauss Hauer & Feld LLP, Houston, TX. Available at <http://www.akingump.com/communicationcenter/newsalertdetail.aspx?pub=2996> (accessed April 23, 2012).
- Argote, L. 1999. *Organizational Learning: Creating, Retaining and Transferring Knowledge*. Springer, New York, 212 pp.
- Argyris, C., and D.A. Schön. 1978. *Organizational Learning: A Theory of Action Perspective*. Addison-Wesley, Reading, MA, 344 pp.
- Behling, M.C., S. Pool, D.G. Patchen, and J.A. Harper. 2008. *Improving the Availability and Delivery of Critical Information for Tight Gas Resource Development in the Appalachian Basin*. DOE Award DE-FC26-05NT42661. US Department of Energy, Washington, DC, 27 pp.
- Belieu, S.D., M. J. Paque, and R.J. Simmers. 2001. *An Environmental Information Management Suite for U.S. Oil and Gas Wells*. Paper presented at the Exploration and Production Environmental Conference, Society of Petroleum Engineers, February 26–28, San Antonio, TX, 12 pp.
- Bonham-Carter, G.F. 1994. *Geographic Information Systems for Geoscientists: Modelling with GIS*. Elsevier, Burlington, MA, 416 pp.
- Butts, C. 1918. Geologic Section of Blair and Huntingdon Counties, Central Pennsylvania. *American Journal of Science* 46(273):523–537.
- Cahoy, D.R., J. Gehman, and Z. Lei. Forthcoming. Fracking Patents: The Emergence of Patents as Information Containment Tools in Shale Drilling. *Michigan Telecommunications and Technology Law Review*.
- Callon, M., P. Lascoumes, and Y. Barthe. 2009. *Acting in an Uncertain World: An Essay on Technical Democracy*. Inside Technology. Cambridge, MA, MIT Press, 298 pp.
- Carnegie Museum of Natural History. 2012, rev. June. *Pennsylvania Unconventional Natural Gas Wells Geodatabase* (computer file). Carnegie Museum of Natural History, Pittsburgh, PA, 10 pp. Available at http://www.carnegiemnh.org/assets/science/pnr/UnconventionalWells_Metadata.pdf (accessed October 27, 2012).
- Carter, K.M. 2007. *Subsurface Rock Correlation Diagram, Oil and Gas Producing Regions of Pennsylvania*. Pennsylvania Geological Survey, 4th series, Open-File Report OFOG 07-01.1. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 1 p. Available at <http://www.dcnr.state.pa.us/topogeo/drc/index.aspx> (accessed April 10, 2012).

- Colborn, T., C. Kwiatkowski, K. Schultz, and M. Bachran. 2011. Natural Gas Operations from a Public Health Perspective. *Human and Ecological Risk Assessment* 17(5):1039–1056.
- Corbett, T. 2011. *Creation of Governor's Marcellus Shale Advisory Commission*. Executive Order 2011–01. Commonwealth of Pennsylvania, Office of the Governor, Harrisburg, PA, 137 pp. Available at http://files.dep.state.pa.us/publicparticipation/marcellusshaleadvisorycommission/marcellusshaleadvisoryportalfiles/msac_final_report.pdf (accessed April 12, 2012).
- Cozart, C.L., and J.A. Harper. 1993. *Oil and Gas Developments in Pennsylvania in 1991*. Pennsylvania Geological Survey, 4th series, Progress Report 205. Pennsylvania Department of Environmental Resources, Harrisburg, PA, 96 pp.
- Detrow, S. 2012a. Commonwealth Court: Act 13's Zoning Restrictions Are Unconstitutional. *StateImpact Pennsylvania*, July 26.
- Detrow, S. 2012b. Court Bars Public Utility Commission from Reviewing Drilling Ordinances. *StateImpact Pennsylvania*, October 26.
- Detrow, S. 2012c. Mapping Pennsylvania's Impact Fee Revenue (This Time, Officially). *StateImpact Pennsylvania*, April 30.
- Edelman, L.B., C. Uggen, and H.S. Erlanger. 1999. The Endogeneity of Legal Regulation: Grievance Procedures as Rational Myth. *American Journal of Sociology* 105(2):406–454.
- Etzion, D., and F. Ferraro. 2010. The Role of Analogy in the Institutionalization of Sustainability Reporting. *Organization Science* 21(5):1092–1107.
- Fischetti, M. 2010. The Drillers Are Coming. *Scientific American* 303(1):82–85.
- Gallagher, H., and D. Song. 2011. Mandatory Greenhouse Gas Reporting: Are You Sure You Are Not Applicable? *Environmental Practice* 13(2):122–129.
- Garud, R., and J. Gehman. 2012. Metatheoretical Perspectives on Sustainability Journeys: Evolutionary, Relational And Durational. *Research Policy* 41(6):980–995.
- Garud, R., J. Gehman, and A. Kumaraswamy. 2011. Complexity Arrangements for Sustained Innovation: Lessons from 3M Corporation. *Organization Studies* 32(6):737–767.
- Hamill, S.D. 2012. Drilling Numbers Do Not Add Up. *Pittsburgh Post-Gazette*, January. 8.
- Harper, J.A. 1982. *Oil and Gas Developments in Pennsylvania in 1981*. Pennsylvania Geological Survey, 4th series, Progress Report 195. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 116 pp.

- Harper, J.A. 1986. *Oil and Gas Developments in Pennsylvania in 1986*. Pennsylvania Geological Survey, 4th series, Progress Report 200. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 93 pp.
- Harper, J.A. 2008. The Marcellus Shale: An Old “New” Gas Reservoir in Pennsylvania. *Pennsylvania Geology* 38(1):2–13.
- Harper, J.A., and C.L. Cozart. 1988. *Oil and Gas Developments in Pennsylvania in 1987*. Pennsylvania Geological Survey, 4th series, Progress Report 201. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 80 pp.
- Harper, J.A., and C.L. Cozart. 1992. *Oil and Gas Developments in Pennsylvania in 1990 with Ten-Year Review and Forecast*. Pennsylvania Geological Survey, 4th series, Progress Report 204. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 85 pp.
- Howarth, R., R. Santoro, and A. Ingraffea. 2011. Methane and the Greenhouse Gas Footprint of Natural Gas from Shale Formations. *Climatic Change* 106(4):679–690.
- Johnson, N., T. Gagnolet, R. Ralls, E. Zimmerman, B. Eichelberger, C. Tracey, G. Kreitler, S. Orndorff, J. Tomlinson, S. Bearer, and S. Sargent. 2010, November 15. *Pennsylvania Energy Impacts Assessment: Report 1—Marcellus Shale Natural Gas and Wind*. The Nature Conservancy, Arlington, VA, 46 pp. Available at http://www.shalegas.energy.gov/resources/tnc_energy_analysis.pdf (accessed April 12, 2012).
- Kelley, D.R., W.S. Lytle, W.R. Wagner, and L. Heyman. 1969. *Oil and Gas Developments in Pennsylvania in 1968*. Pennsylvania Geological Survey, 4th series, Progress Report 177. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 48 pp.
- Kimmel, S.L., and P.F. Fulton. 1983. *Results of Pressure Transient Well Testing in Appalachian Gas Reservoirs*. Paper presented at the Eastern Regional Meeting, Society of Petroleum Engineers, November 9–11, Pittsburgh, PA, 12 pp.
- Kirr, J.N., G.E. Eddy, C.D. Locke, and J.B. Smith. 1986. *Geology and Production Potential of the Devonian Rhinestreet Shale: A Case Study of Three Wells*. Paper presented at the Society of Petroleum Engineers Unconventional Gas Technology Symposium, May 18–21, Louisville, KY, 14 pp.
- Kunce, M., and W.E. Morgan. 2005. Taxation of Oil and Gas in the United States 1970–1997. *Natural Resources Journal* 45(1):77–101.
- Levine, M.E., and J.L. Forrence. 1990. Regulatory Capture, Public Interest, and the Public Agenda: Toward a Synthesis. *Journal of Law, Economics, & Organization* 6 (special issue):167–198.

- Lytle, W.S., L. Heyman, and W.R. Wagner. 1967. *Oil and Gas Developments in Pennsylvania in 1966*. Pennsylvania Geological Survey, 4th series, Progress Report 173. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 51 pp.
- Mamoulis, N. 2012. *Spatial Data Management*. Morgan & Claypool, San Rafael, CA, 150 pp.
- Marcellus Center for Outreach and Research. 2012. *Marcellus Shale Wells*. Pennsylvania State University, University Park, PA. Available at <http://www.marcellus.psu.edu/images/Wells-all.gif> (accessed April 27, 2012).
- Marcellus Shale Advisory Commission (MSAC). 2011, July 22. *Governor's Marcellus Shale Advisory Commission Final Report*. Commonwealth of Pennsylvania, Office of the Governor, Harrisburg, PA, 137 pp. Available at http://files.dep.state.pa.us/publicparticipation/marcellusshaleadvisorycommission/marcellusshaleadvisoryportalfiles/msac_final_report.pdf (accessed April 12, 2012).
- McKenzie, L.M., R.Z. Witter, L.S. Newman, and J.L. Adgate. 2012. Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources. *Science of the Total Environment* 424:79–87.
- Meyer, M.W., and L.G. Zucker. 1989. *Permanently Failing Organizations*. Sage, Newbury Park, CA, 192 pp.
- Mooney, C. 2011. The Truth about Fracking. *Scientific American* 305(5):80–85.
- National Research Council. 2012. *Advancing Strategic Science: A Spatial Data Infrastructure Roadmap for the U.S. Geological Survey*. National Academies Press, Washington, DC, 115 pp.
- O'Keefe, B. 2012. Exxon's Big Bet on Shale Gas. *Fortune*, April 30, pp. 75–86.
- Osborn, S.G., A. Vengosh, N.R. Warner, and R.B. Jackson. 2011. Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing. *Proceedings of the National Academy of Sciences, USA* 108(20):8172–8176.
- Ostrom, E. 1990. *Governing the commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, New York, 298 pp.
- Patchen, D.G., K.A. Schwarz, T.H. DeBrosse, E.P. Bendler, J.B. Hermann, J.A. Harper, W.W. Kelly, and K.L. Avary. 1981. Northeastern United States. *AAPG Bulletin* 65(10):1896–1929.
- Patchen, D., K.A. Schwarz, T.A. DeBrosse, E.P. Bendler, M.P. McCormac, J.A. Harper, W.W. Kelly, and K.L. Avary. 1984. Oil and Gas Developments in Mid-Eastern States in 1983. *AAPG Bulletin* 68(10):1383–1399.

- Pennsylvania Department of Environmental Protection (PA DEP). 2000, April 10. *Pennsylvania's Plan for Addressing Problem Abandoned Wells and Orphaned Wells*. Document 550-0800-001. PA DEP Bureau of Oil and Gas Management, Harrisburg, PA, 8 pp. Available at <http://www.elibrary.dep.state.pa.us/dsweb/Get/Version-48262/550-0800-001.pdf> (accessed May 4, 2012).
- Pennsylvania Department of Environmental Protection (PA DEP). 2011a, November 14. *Internal Review of Inspection and Enforcement of Natural Gas Operations*. PA DEP, Harrisburg, PA, 10 pp. Available at <http://files.dep.state.pa.us/OilGas/OilGasLandingPageFiles/NOV/FINALMarcellusEnforcementProjectFindings.pdf> (accessed May 4, 2012).
- Pennsylvania Department of Environmental Protection (PA DEP). 2011b, rev. March. *Oil and Gas Well Drilling and Production in Pennsylvania*. Document 5500-FS-DEP2018. PA DEP, Harrisburg, PA, 3 pp. Available at <http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-83620/5500-FS-DEP2018.pdf> (accessed April 10, 2012).
- Pennsylvania Department of Environmental Protection (PA DEP). 2012a. *Act 13 Frequently Asked Questions*. PA DEP, Harrisburg, PA, 8 pp. Available at http://files.dep.state.pa.us/OilGas/OilGasLandingPageFiles/Act13/Act_13_FAQ.pdf (accessed April 10, 2012).
- Pennsylvania Department of Environmental Protection (PA DEP). 2012b, March 27. *Act 13 Overview Webinar*. PA DEP, Harrisburg, PA. Available at http://www.depweb.state.pa.us/portal/server.pt/community/act_13/20789 (accessed April 10, 2012).
- Pennsylvania Department of Environmental Protection (PA DEP). 2012c, rev. April. *Instructions for Completing an Application for a Permit to Drill or Alter an Oil and Gas Well*. PA DEP, Harrisburg, PA, 10 pp. Form 8000-PM-OOGM0001. Available at <http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-87960/8000-PM-OOGM0001%20Instructions.pdf> (accessed April 10, 2012).
- Pennsylvania Department of Environmental Protection (PA DEP). 2012d. *Public Utility Commission Act 13 Unconventional Wells Spud Report through December 31, 2011*. PA DEP, Harrisburg, PA, 206 pp. Available at http://files.dep.state.pa.us/OilGas/OilGasLandingPageFiles/Act13/PUC_2011_Web.pdf (accessed March 14, 2012).
- Pennsylvania Public Utility Commission (PA PUC). 2012a, May 10. *Chapter 23 Final Order*. PA PUC, Harrisburg, PA, 20 pp. Docket No. M-2012-2288561.
- Pennsylvania Public Utility Commission (PA PUC). 2012b, September 13. *Impact Fee Implementation*. PA PUC, Harrisburg, PA, 20 pp. Available at

- http://www.puc.state.pa.us/NaturalGas/pdf/MarcellusShale/Act13_Implementation_Presentation.pdf (accessed October 27, 2012).
- Pennsylvania Public Utility Commission (PA PUC). 2012c, July 19. *Reconsideration Order Regarding Chapter 23*. PA PUC, Harrisburg, PA, 10 pp. Docket No. M-2012-2288561.
- Piotrowski, R.G. 1980. *Oil and Gas Developments in Pennsylvania in 1979*. Pennsylvania Geological Survey, 4th series, Progress Report 193. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA, 64 pp.
- PPDM. 2012. *PPDM Standards*. PPDM, Calgary, Canada. <http://www.ppdm.org/ppdm-standards> (accessed May 9, 2012).
- Rabe, B.G., and C.P. Borick. 2012, rev. June 1. *The Conventional Politics of Unconventional Drilling: The Case of Shale Gas Development in Pennsylvania*. 26 pp. <http://ssrn.com/abstract=1908747> (accessed September 6, 2012).
- Rushing, J.A., K.E. Newsham, and T.A. Blasingame. 2008. *Rock Typing: Keys to Understanding Productivity in Tight Gas Sands*. Paper presented at the Society of Petroleum Engineers Unconventional Reservoirs Conference, February 10–12, Keystone, CO, 31 pp.
- Ryder, R.T. 2004. *Stratigraphic Framework and Depositional Sequences in the Lower Silurian Regional Oil and Gas Accumulation, Appalachian Basin: From Ashland County, Ohio, through Southwestern Pennsylvania, to Preston County, West Virginia*. US Geological Survey, Geologic Investigations Series, Map I-2810. US Department of the Interior, US Geological Survey, Washington, DC.
- TGS. 2012. *Marcellus Well Log Formation Top Interpretation*. TGS, Houston, TX, 1 p. Available at http://www.tgs.com/uploadedFiles/Geological_Zone/Well_Log_Data/Formation_Tops/Marcellus%20Formation%20Tops.pdf (accessed May 6, 2012).
- Thornton, P.H., W. Ocasio, and M. Lounsbury. 2012. *The Institutional Logics Perspective: A New Approach to Culture, Structure, and Process*. Oxford University Press, New York, 250 pp.
- US Energy Information Administration (EIA). 2011, July. *Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays*. US Department of Energy, Washington, DC, 82 pp.
- US Energy Information Administration (EIA). 2012, June 25. *Annual Energy Outlook 2012 Early Release Overview*. DOE/EIA-0383ER(2012). US Department of Energy, Washington, DC, 239 pp.
- Volz, C.D., K. Ferrar, D. Michanowicz, C. Christen, S. Kearney, M. Kelso, and S. Malone. 2011. *Contaminant Characterization of Effluent from Pennsylvania Brine Treatment Inc., Josephine Facility: Implications for Disposal of Oil and Gas Flowback Fluids from Brine*

Treatment Plants. US EPA Hydraulic Fracturing Study Technical Workshop 3: Fate and Transport. Indiana University of Pennsylvania, Indiana, PA, 28 pp.

Whitacre, J.V., and J.W. Wenzel. 2011. *Publically Available Records Do Not Indicate Marcellus Wells Reliably*. Paper presented at the Pennsylvania Geographical Society Annual Meeting, November 4–5, Indiana University of Pennsylvania, Indiana, PA.

Wylde, J.J., and B.J. O’Neil. 2011. *Environmentally Acceptable Replacement of 2-Butoxyethanol: A High Performance Alternative for Fracturing Applications*. Paper presented at the Society of Petroleum Engineers International Symposium on Oilfield Chemistry, April 11–13, The Woodlands, TX, 16 pp.

FIGURE 1

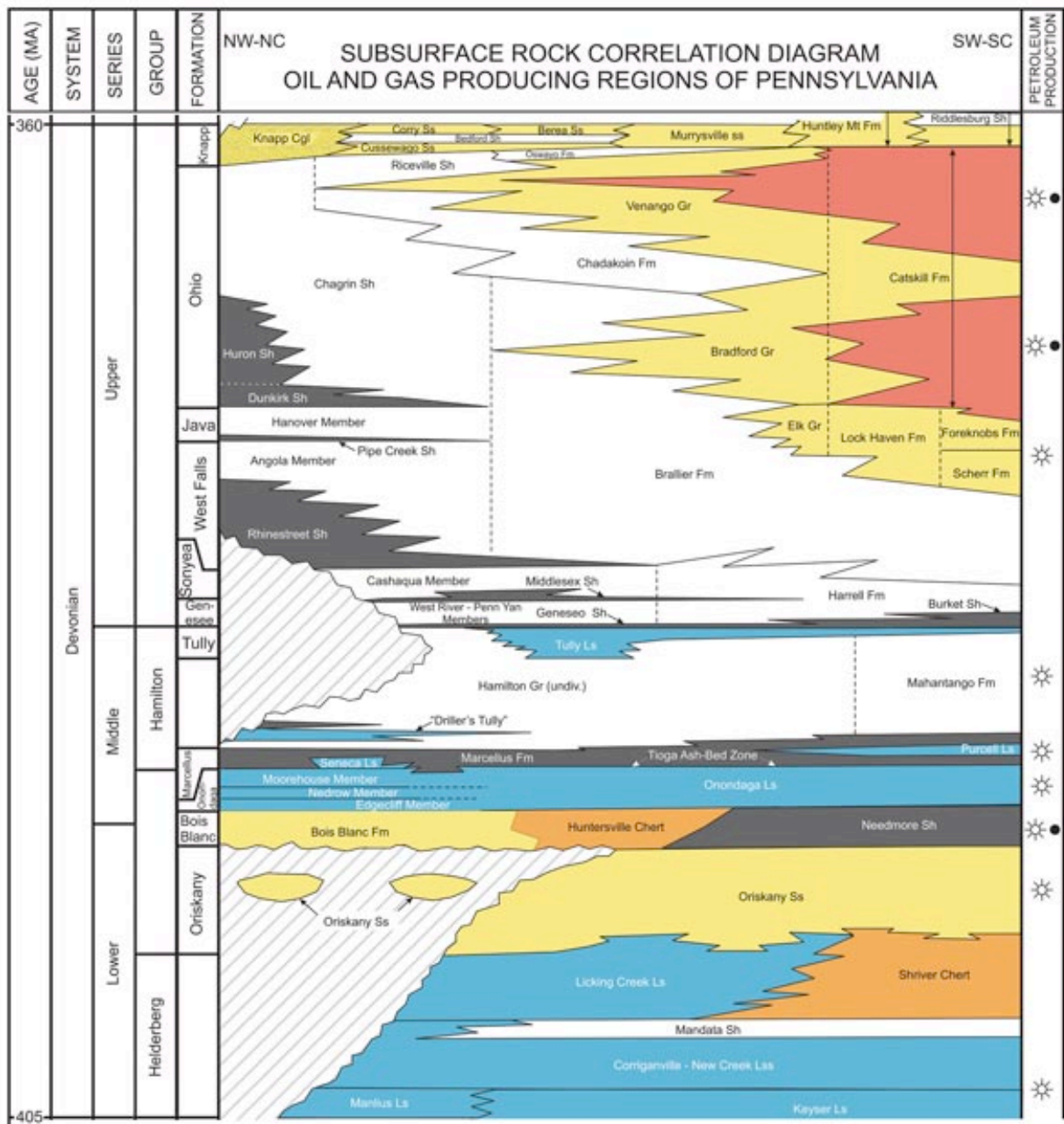


Figure 1. Devonian age subsurface rock correlation diagram (adapted with permission from Carter, 2007).

FIGURE 2

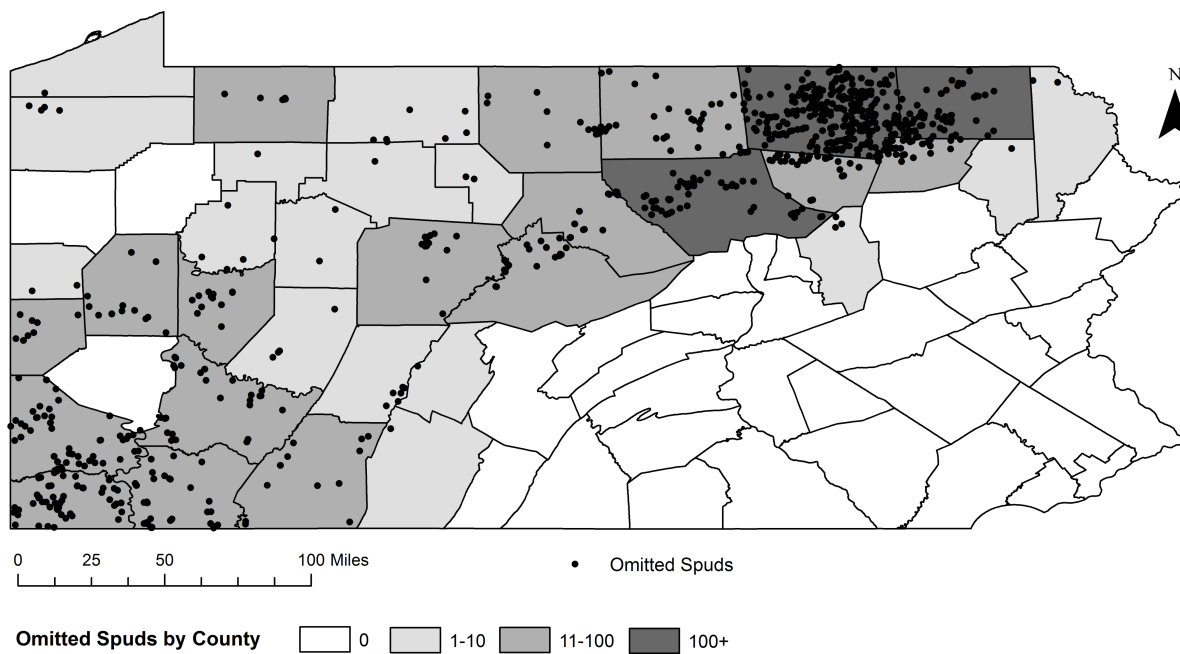


Figure 2. Map of omitted *recent* unconventional gas wells spud in Pennsylvania through December 31, 2011.

FIGURE 3

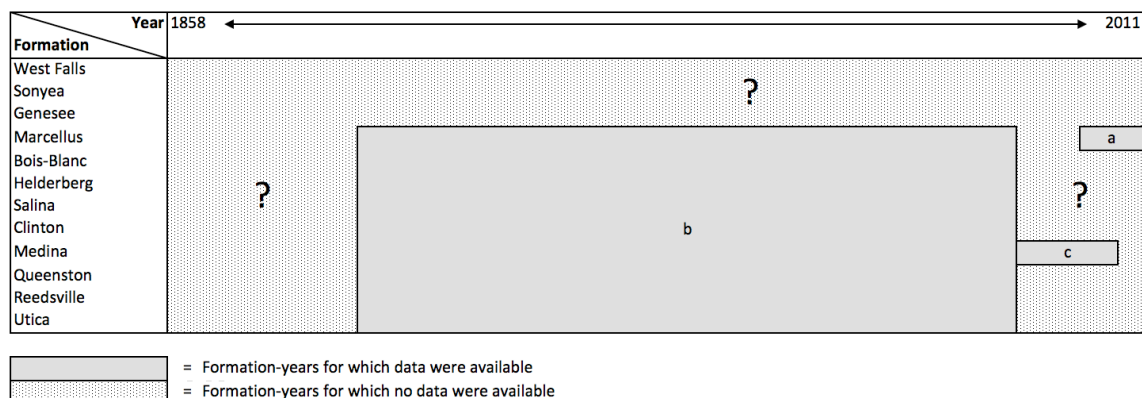


Figure 3. Summary of data limitations. This figure is drawn to scale (i.e., the total area of cells for which data are available is 962 formation-years vs. 886 for the cells for which no data were available). **a:** Department of Environmental Protection data available for Marcellus wells from 2002 to 2011. **b:** Bureau of Topographic and Geological Survey data available for selected *deep* wells from 1888 to 1991. **c:** Appalachian Basin Tight Gas Reservoirs Project data available for Medina wells from 1992 to 2007.

TABLE 1. SHALE FORMATIONS BELOW THE ELK SANDSTONE

System (age)	Formation or group (shale)
Devonian (360 Ma)	West Falls (Rhinestreet) Sonyea (Middlesex) Genesee (Burket; Geneseo) Marcellus (Marcellus) Bois-Blanc (Needmore) Helderberg (Mandata)
Silurian (405 Ma)	Salina (Camillus; E; C; Willis Creek) Clinton (Rochester; Rose Hill) Medina (Cabot Head)
Ordovician (430 Ma)	Queenston (Queenston; Juniata) Reedsville (Reedsville) Utica (Utica; Antes)

Source: Adapted from Carter (2007). "Ma" is mega-annum, or a million years.

TABLE 2. SUMMARY OF THE ACT 13 REPORT FROM THE PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION (PA DEP)

Formation	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Totals
Burket							1			5	6
Geneseo									1		1
Mandata										1	1
Marcellus	1	2	1	6	34	107	324	815	1,613	1,984	4,887
Rhinestreet								1	2	1	4
Utica										7	7
<i>Totals</i> ^a	1	2	1	6	34	107	325	816	1,616	1,998	4,906

Source: This table is based on an analysis of the DEP's Act 13 report as generated on March 1, 2012, at 9:45 a.m. (PA DEP, 2012d). Please see the accompanying text for a complete description.

^a Spud dates were available for 4,718 of the 4,906 wells in the DEP's Act 13 report. On average, these wells were spud 67 days after their last permit date. Accordingly, we imputed spud dates for 187 wells by using this formula: spud date = last permit date + 67 days. One well had no reported permit or spud date, so we arbitrarily assigned it to 2011. These decisions are inconsequential to our analysis as all wells spud prior to the passage of Act 13 are considered spud in 2011.

TABLE 3. COMPARISON OF THE OIL AND GAS REPORTS FROM THE PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION (PA DEP) THROUGH 2011

Unconventional spud wells	DEP's Act 13 report	DEP's oil & gas reports
From Act 13 report	4,906	4,906
From spuds table	—	386
From production table	—	934
From wastes table	—	120
From compliance table	—	84
Total spud wells	4,906	6,430

Sources: This table is based on an analysis of publicly available DEP reports (Act 13, permits, spuds, production, wastes, and compliance) and covers the period through December 31, 2011. The reports were imported into a Structured Query Language (SQL) database and American Petroleum Institute (API) well numbers were used as unique identifiers. Please see the accompanying text for a complete description.

TABLE 4. OMITTED UNCONVENTIONAL WELLS BY COUNTY

	Vertical wells, 2002–11^a	Horizontal wells, 2002–11^a	Deep wells, 1888–1991^b	Medina wells, 1992–2007^c	Total omitted wells
Allegheny		3	4		7
Armstrong	10	5	24		39
Beaver		12	24		36
Bedford		1	62		63
Blair		2	9		11
Bradford	12	615	20		647
Bucks			1		1
Butler	6	9	16	11	42
Cambria		5	34		39
Cameron		3	153		156
Carbon			2		2
Centre	3	26	20		49
Clarion	3	2	17		22
Clearfield	4	13	413		430
Clinton	2	24	237		263
Columbia		3	1		4
Crawford		4	1,986	912	2,902
Elk		1	314		315
Erie		1	2,674	66	2,741
Fayette	22	24	94		140
Forest	1		12		13
Fulton			5		5
Greene	17	77	4		98
Indiana	5		159		164
Jefferson	2		88		90
Juniata			4		4
Lackawana		1	2		3
Lawrence	1	2	11	192	206
Lucerne			3		3
Lycoming	29	91	22		142
McKean	4	3	54		61
Mercer			674	1,925	2,599
Mifflin			2		2
Montgomery			1		1
Northumberland			6		6
Pike			3		3
Potter	4	9	526		539
Snyder			3		3
Somerset	7	8	147		162

Sullivan	1	67	4		72
Susquehanna	21	91	4		116
Tioga	12	42	232		286
Venango			722	544	1,266
Union			3		3
Warren	2	10	820	388	1,220
Washington	17	63	17		97
Wayne	1	1	6		8
Westmoreland	7	34	114		155
Wyoming	1	78	3		82
York			3		3
<i>Totals</i>	194	1,330	9,759	4,038	15,321

Note: Please see the accompanying text for a complete description.

^a Based on our analysis of the Pennsylvania Department of Environmental Protection's publicly available Act 13, permits, spuds, production, wastes, and compliance reports through December 31, 2011.

^b Based on our analysis of well records published by the Bureau of Topographic and Geological Survey covering 1888–1991 (the date range for which these data are available). See Bureau Bulletins M31, M39, and M49, and Progress Reports for 1960–91.

^c Based on our analysis of Medina well records compiled by the Appalachian Basin Tight Gas Reservoirs Project for the period from 1992 to early 2007 (the date range for which these data are available and do not overlap with the Bureau's deep well data).

TABLE 5. ESTIMATED FINANCIAL CONSEQUENCES OF OMITTED WELLS

Wells included	Minimal fees, due in 2012	Cumulative fees, if wells nonproductive within 2 years^a	Cumulative fees, if wells unplugged for 10 or 15 years^b
Known wells ^c ~1,300 horizontal wells @ \$50,000 ~14,000 vertical wells @ \$10,000	~\$205 million	~\$431–636 million	~\$0.75–\$1.27 billion
Probable wells ^d All of the above, plus ~9,800 vertical wells @ \$10,000	~\$303 million	~\$636–939 million	~\$1.09–\$1.85 billion

Note: Please see accompanying text for a complete description of all estimates, the Online Supplement for detailed calculations, and note 14 for a discussion of the PUC's revised treatment of vertical wells.

^a Assumes that within two years after paying the initial fee all wells are incapable of producing more than 90,000 cubic feet of gas per day (90 mcfpd), resulting in the suspension of subsequent fees.

^b Assumes that all wells are not incapable of producing 90 mcfpd within 2 years after paying the initial fee and are not plugged for 15 years in the case of horizontal wells and 10 years in the case of vertical wells.

^c Based on our analysis of data from the Pennsylvania Department of Environmental Protection, the Bureau of Topographic and Geologic Survey and the Appalachian Basin Tight Gas Reservoirs Project. These wells can be identified by name, number, and location.

^d Based on our analysis of the above data sources and the assumption that data from the Bureau underreported the number of deep wells spud during 1888–1991 by a factor of 2.