Good afternoon Co-chairs Miner and Kennedy and Demicco and members of the Environment Committee:

I am writing in support of HB 6329, which as you know would permanently ban fracking waste and its storage, treatment, disposal or discharge in Connecticut. This bill is an important step to safeguard the residents and environmental resources of our State. While we are currently protected by the temporary moratorium, this bill takes the final action in ban these toxic materials.

In the time since the moratorium was enacted, several municipalities, including Branford have taken action by approving ordinances to ban hazardous fracking waste materials from their borders. By this assessment, thousands of Connecticut citizens have already voiced their support for protecting Connecticut from fracking waste. In Branford alone, scores of citizens submitted written and spoken testimony in support of our local ordinance. The protective ordinance in Branford was especially critical due to a large percentage of our community relying on groundwater wells for drinking water and for beautiful coastal aquatic resources which are utilized by tourists in the summer and wildlife and shellfish throughout the year.

Where fracking waste storage and treatment facilities have been permitted, they have failed, releasing contaminants into the environment. A recent EPA report in 2015 catalogued 457 spill events at these facilities. Over 330 of these spills were related to storage devices, equipment or hoses. The cause of the spill was most often human error (33%) and equipment failure (27%). There is not level of detail in any sort of DEEP permit that can prevent these causes of fracking waste spillage. This data shows why Connecticut must simply eliminate the toxic risk of fracking waste from our State as opposed to attempt to regulate it.

I urge each of your to support the passage of HB6329 and thank you for the opportunity to provide testimony in support of the bill.

Sincerely

Chris Sullivan
18 Pine Hollow Road
Branford, CT 06405

United States
Environmental Protection
Agency

EPA/601/R-14/001 | May 2015 | www.epa.gov/hfstudy

Review of State and Industry Spill Data:

Characterization of Hydraulic Fracturing-Related Spills

United States Environmental Protection Agency
Office of Research and Development

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U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC

May 2015
EPA/601/R-14/001

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Preface

The U.S. Environmental Protection Agency (EPA) is conducting a study of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources. This study was initiated in Fiscal Year 2010 when Congress urged the EPA to examine the relationship between hydraulic fracturing and drinking water resources in the United States. In response, the EPA developed a research plan (*Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*) that was reviewed by the agency's Science Advisory Board (SAB) and issued in 2011. A progress report on the study (*Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: Progress Report*), detailing the EPA's research approaches and next steps, was released in late 2012 and was followed by a consultation with individual experts convened under the auspices of the SAB.

The EPA's study includes the development of several research projects, extensive review of the literature and technical input from state, industry, and non-governmental organizations as well as the public and other stakeholders. A series of technical roundtables and in-depth technical workshops were held to help address specific research questions and to inform the work of the study. The study is designed to address research questions posed for each stage of the hydraulic fracturing water cycle:

- Water Acquisition: What are the possible impacts of large volume water withdrawals from ground and surface waters on drinking water resources?
- Chemical Mixing: What are the possible impacts of surface spills of hydraulic fracturing fluids on or near well pads on drinking water resources?
- Well Injection: What are the possible impacts of the injection and fracturing process on drinking water resources?
- Flowback and Produced Water: What are the possible impacts of surface spills of flowback and produced water on or near well pads on drinking water resources?
- Wastewater Treatment and Waste Disposal: What are the possible impacts of inadequate treatment of hydraulic fracturing wastewaters on drinking water resources?

This report, *Review of State and Industry Spill Data: Characterization of Hydraulic Fracturing-Related Spills*, is the product of one of the research projects conducted as part of the EPA's study. It has undergone independent, external peer review in accordance with agency policy and all of the peer review comments received were considered in the report's development.

The EPA's study will contribute to the understanding of the potential impacts of hydraulic fracturing activities for oil and gas on drinking water resources and the factors that may influence those impacts. The study will help facilitate and inform dialogue among interested stakeholders, including Congress, other Federal agencies, states, tribal government, the international community, industry, non-governmental organizations, academia, and the general public.

Executive Summary

Advances in hydraulic fracturing and horizontal drilling technologies have led to increased oil and gas exploration and production activity in different regions of the United States. Hydraulic fracturing is a technique used to enable or enhance the production of hydrocarbons from underground rock formations. It involves the injection of hydraulic fracturing fluids (typically a mixture of water, proppant, and chemical additives) under pressures great enough to fracture the targeted hydrocarbon-bearing formations. The volumes and chemical compositions of hydraulic fracturing fluids and flowback fluids (i.e., fluids that return to the surface after hydraulic fracturing) managed on oil and gas production well pads have led to concerns about potential human health and environmental impacts from surface spills of these fluids. The objective of this study was to characterize hydraulic fracturing-related spills that may reach surface or ground water resources using spill reports obtained from selected state and industry data sources.

Data gathered from selected state and industry data sources were used to characterize hydraulic fracturing-related spills with respect to volumes and materials spilled, sources and causes of spills, environmental receptors, and spill containment and response activities. For the purposes of the study, hydraulic fracturing-related spills were defined as those occurring on or near the well pad before or during the mixing and injection of hydraulic fracturing fluids or during the post-injection recovery of fluids. Because the main focus of this study was to characterize hydraulic fracturing-related spills on the well pad that may reach surface or ground water resources, the following topics were not included: transportation-related spills, drilling mud spills, and spills associated with disposal through underground injection control wells.

Data on spills that occurred between January 2006 and April 2012 were obtained from nine states with online spill databases or other data sources, nine hydraulic fracturing service companies, and nine oil and gas production well operators. The data sources used in this study contained over 36,000 spills. Spill records from an estimated 12,000 spills (33 percent of the total number of spills reviewed) contained insufficient information to determine whether the spill was related to hydraulic fracturing. Of the spills with sufficient information, the EPA identified an estimated 24,000 spills (66 percent) as not related to hydraulic fracturing and 457 spills (approximately 1 percent) as related to hydraulic fracturing. The 457 hydraulic fracturing-related spills occurred in 11 different states over the period of time studied.

For the 457 hydraulic fracturing-related spills included in the study, the most commonly reported information obtained from state and industry data sources was the type of material spilled (reported in 97 percent of the hydraulic fracturing-related spills), followed by the volume spilled and then the source and cause of the spill. In approximately 90 percent of the hydraulic fracturing-related spills, information was available on whether or not spilled fluids reached at least one environmental receptor (surface water, ground water, and/or soil). The EPA did not determine whether spilled fluids affected the quality of surface or ground water resources.

The hydraulic fracturing-related spills were characterized by numerous low volume spills (up to 1,000 gallons) and relatively few high volume spills (greater than 20,000 gallons). The most common material spilled was flowback and produced water, and the most common source of spills

1. Objective

The objective of this study was to characterize hydraulic fracturing-related spills that may reach surface or ground water resources using spill reports obtained from selected state and industry data sources. For the purposes of the study, hydraulic fracturing-related spills were defined as those occurring on or near the well pad before or during the mixing and injection of hydraulic fracturing fluids or during the post-injection recovery of fluids. This study did not determine if or how spilled fluids may have affected surface or ground water quality, nor did it evaluate spill reporting requirements.

The analysis described in this report was conducted in support of the U.S. Environmental Protection Agency's (EPA) *Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources* (US EPA, 2011a). The *Study Plan* identified the importance of understanding the possible impacts on drinking water resources from surface spills of hydraulic fracturing fluids or flowback and produced water on or near well pads. The analysis presented in this report provides information on volumes and materials spilled, sources and causes of spills, environmental receptors, and spill containment and response activities for hydraulic fracturing-related spills.

2. Introduction

Hydraulic fracturing is a technique used to enable or enhance the production of hydrocarbons from underground rock formations. It involves the injection of hydraulic fracturing fluids (typically a mixture of water, proppant, and chemical additives) under pressures great enough to fracture the targeted hydrocarbon-bearing formations (Gregory et al., 2011; Vidic et al., 2013). After the injection pressure is released, fluids flow through the fractures back out of the well, leaving behind proppants (often fine-grained sand) that hold open the newly-created fractures. The fractures allow oil and gas to flow from pores within the formation to the production well [Ground Water Protection Council (GWPC) and ALL Consulting, 2009; Soeder, 2010].

On-site fluid management is a typical practice associated with hydraulic fracturing. Hydraulic fracturing base fluids, most commonly water, are typically stored in large volume tanks on the well pad. Chemicals additives can be stored on a flatbed truck or van enclosure that holds a number of chemical totes. The most common chemical totes are 200 to 400 gallon polyethylene containers (New York State Department of Environmental Conservation, 2011). Pumps and hoses are used to move the base fluid and chemical additives to a blender that mixes the fluids. The fluid is then transferred to a manifold for delivery to the wellhead for injection (Malone and Ely, 2007). As fluids are transferred and moved around the well pad and through various pieces of equipment, faulty equipment or human error may create opportunities for spills of the various components of fracturing fluid (Colorado Department of Natural Resources, 2014).

The type and amount of fluids stored on-site is largely determined by the characteristics of the formation being fractured, as well as by economics, production goals, and availability of chemical additives. Estimates of water needs per well have been reported to range from 50,000 gallons for coalbed methane production to 13 million gallons for shale gas production (US EPA, 2004; Vengosh et al., 2014). Approximately 1 to 2 percent or less of the volume of water-based hydraulic fracturing

3. Methods

3.1. Data Sources

Data used in this study were obtained from both state and industry data sources.[1] States often maintain spill databases or spill records that are designed to track inspection results, complaints, and/or violations. These spills can be associated with a wide variety of activities, including, but not limited to, hydraulic fracturing. Incidents found in state data sources are typically self-reported or can be identified through citizen complaints and routine inspections by state officials.

States were selected based on the number of oil and gas wells that were reported by nine oil and gas service companies to have been hydraulically fractured between approximately September 2009 and September 2010 (US EPA, 2012).[2] The EPA used the service company information to identify the ten states with the most hydraulic fracturing activity reported during that time period: Arkansas, Colorado, Louisiana, New Mexico, North Dakota, Oklahoma, Pennsylvania, Texas, Utah, and Wyoming. State spill data sources were identified for all states except North Dakota.[3] Online, publicly accessible spill databases were identified for Arkansas, Colorado, New Mexico, and Pennsylvania. Offline, publicly accessible spill data were obtained from Louisiana, Oklahoma, Texas, Utah, and Wyoming. The state spill data sources varied in accessibility, searchability, and the types of information available. Table 1 summarizes the data elements (e.g., volume spilled, spill cause) available for each state data source.

Industry data were obtained from responses to information requests that were sent to nine hydraulic fracturing service companies[4] and nine oil and gas well operators[5] in September 2010 and August 2011, respectively (US EPA, 2010, 2011c).[6] Although the service companies were not specifically asked for information on spills, some companies provided information relevant for this report. The EPA asked the well operators for spill reports associated with 350 well identifiers corresponding to wells that were reported to have been hydraulically fractured between approximately September 2009 and September 2010. Some of the industry data were submitted as confidential business information under the Toxic Substances Control Act. The EPA worked with

[1] Information on spills can also be obtained from the U.S. Coast Guard's National Response Center. The National Response Center records information on oil spills, chemical releases, and maritime security incidents. Data sources maintained by states were considered more appropriate for this study.

[2] The nine hydraulic fracturing service companies included: BJ Services Company; Complete Production Services, Inc.; Halliburton Energy Services, Inc.; Key Energy Services; Patterson-UTI Energy; RPC, Inc.; Schlumberger Technology Corporation; Superior Well Services; and Weatherford International. The companies reflected a range of company sizes and geographic diversity (US EPA, 2011a, 2012).

[3] No central database from North Dakota was available at the time of this research. The North Dakota Department of Health now records and makes reports available at www.ndhealth.gov/EHS/Spills/.

[4] See footnote 2.

[5] The nine oil and gas operators included: Clayton Williams Energy, Inc.; ConocoPhillips; EQT Corporation; Hogback Exploration, Inc.; Laramie Energy II, LLC; MDS Energy, Ltd.; Noble Energy, Inc.; SandRidge Exploration and Production, LLC; and Williams Production Company, LLC. The operators had wells in diverse geographic areas and were chosen to reflect a range of company sizes (US EPA, 2012).

[6] The Paperwork Reduction Act of 1995 limits the number of information requests to nine entities per set of queries, unless pre-approved by the Office of Management and Budget.

the service companies and well operators to summarize and present the data used in this report in a way that protects their claims of confidentiality.

3.2. Search Methods

Data sources were initially searched to identify spills that occurred between January 1, 2006, and April 30, 2012. This timeframe encompassed a period of rapid increase in hydraulic fracturing across the United States (US Government Accountability Office, 2014).

Each data source was searched separately because of differences among data sources. Data sources were searched using a combination of available filters (e.g., material spilled), keywords, and line-by-line reviews, depending on the searchability of each data source. Keywords included, but were not limited to: "hydraulic fracturing," "frac," "flowback," "guar gum," "glycol," "quartz," "hydrochloric acid," and some names of companies known to conduct hydraulic fracturing activities. The list of keywords was revised as each data source was searched. Keyword searches also depended on the available search methods because some data sources used fixed terms for certain fields. For example, the New Mexico Oil and Conservation Division Spills Database had fixed terms for the "spill material" field that included "gelled brine (frac fluid)" and "produced water," but not "flowback."

Incident descriptions of all spills within the study timeframe and identified through filters, keyword searches, and line-by-line reviews were reviewed to determine whether the spill was related to hydraulic fracturing and occurred on or near the well pad.[7] Spills were identified as related to hydraulic fracturing if the incident description indicated that the spill occurred immediately before or during mixing and injection of hydraulic fracturing fluids, or during flowback. Hydraulic fracturing-related spills were generally identified through the use of "hydraulic fracturing," "fracking," or "flowback" in incident descriptions. Spills were also identified as related to hydraulic fracturing if chemical additives identified in the reports were specific to hydraulic fracturing activities (e.g., crosslinkers or gelling agents).

After identifying hydraulic fracturing-related spills within the study's scope, each state, service company, and well operator was given a list of spills compiled from its own data. Each data owner reviewed the data and provided further information where possible, including identifying spills that had been incorrectly designated as being related to hydraulic fracturing. These spills were removed and not included in any analyses.

Search Limitations. Searching individual state data sources by keywords has limitations. While common spelling variations were applied for various keywords (e.g., "frac," "frack," and "frak"), incidents could have been missed if a word was incorrectly spelled within the data source (e.g., "glycal" instead of "glycol"). Additionally, a more expansive list of keywords may have identified additional spills that could have been related to hydraulic fracturing.

[7] Because the main focus of this study was to characterize hydraulic fracturing-related spills on the well pad that may reach surface or ground water resources, the following topics were not included: transportation-related spills, drilling mud spills, and spills associated with disposal through underground injection control wells.

3.4. Quality Assurance and Quality Control

The EPA does not make any claims as to the quality or accuracy of the data gathered from the state and industry data sources used in this study. Quality assurance and quality control measures were used to ensure that the analyses performed were properly conducted and that the data used in this report accurately represent the original data obtained from state and industry data sources.

Data from each state source were evaluated by a single reviewer to identify spills potentially related to hydraulic fracturing. Those spills categorized as "related to hydraulic fracturing" were then reviewed by a small group of additional reviewers. For each spill, the group of reviewers reached a consensus about whether the spill could be identified as related to hydraulic fracturing based on the information provided in the spill reports. As noted in Section 3.2, all data owners were offered an opportunity to review their data and provide updated or additional information, including identifying spills incorrectly designated as related to hydraulic fracturing. Approximately six percent of the spills were identified by the data owners as unrelated to hydraulic fracturing and were subsequently removed from Appendix B.

Each field of Appendix B was standardized by a single reviewer. A second individual conducted a complete review of the standardization. Any differences were resolved by both reviewers looking at the original data. Lastly, the final, standardized data were compared with the original data and any discrepancies were addressed. States and companies were also provided a draft of the categorization methods for comment; their comments were considered during the development of the table used for analysis (Appendix B).

Additional quality assurance information on this project can be found in the *Quality Assurance Project Plan for Hydraulic Fracturing Surface Spills Data Analysis,* which was approved on August 2, 2012, and was later updated on September 9, 2013 (US EPA, 2013). The project underwent a technical systems audit by the designated EPA Quality Assurance Manager on August 27, 2012, and no corrective actions were identified.

4. Results: Spill Characterization

The EPA reviewed an estimated 36,000 spills that were reported in the state and industry data sources during the study's timeframe. Roughly 66 percent of the spills were determined to be not related to hydraulic fracturing (Figure 1), and approximately 1 percent (457) of the spills were identified as being related to hydraulic fracturing. Information available for an estimated 33 percent of the approximately 36,000 spills reviewed was insufficient to determine whether or not the spill was associated with hydraulic fracturing.

The 457 hydraulic fracturing-related spills in this analysis occurred in 11 states (Table 2) over six years.[10] State data sources identified a total of 394 hydraulic fracturing-related spills, and industry sources identified 63 additional spills related to hydraulic fracturing. Data provided by industry

[10] The reported number of hydraulic fracturing-related spills per year increased from approximately 27 spills in 2006 to 110 spills in 2011. The increase over this timeframe could have been related to an increase in hydraulic fracturing as well as changes in state reporting requirements and industry reporting trends.

Information System were the most detailed spill reports from among the state data sources used in this analysis and generally provided more of the information needed to determine whether a spill was related to hydraulic fracturing (Table 1). Because of the preponderance of Colorado data, the results presented below are more representative of hydraulic fracturing-related spills that were identified from the Colorado Oil and Gas Information System than of spills identified from other state and industry data sources.

Information from each hydraulic fracturing-related spill was analyzed to describe the following spill characteristics: volumes and materials spilled, sources and causes of spills, and environmental receptors. The availability of reported information on each of these characteristics is shown in Figure 2. Data were not always available for each spill characteristic for each spill. For example, the material spilled was reported in almost all instances, but fewer than half of the reports for each spill included the amount of fluid recovered. The inconsistent data mean that results from analyses of certain spill characteristics are more robust than others.

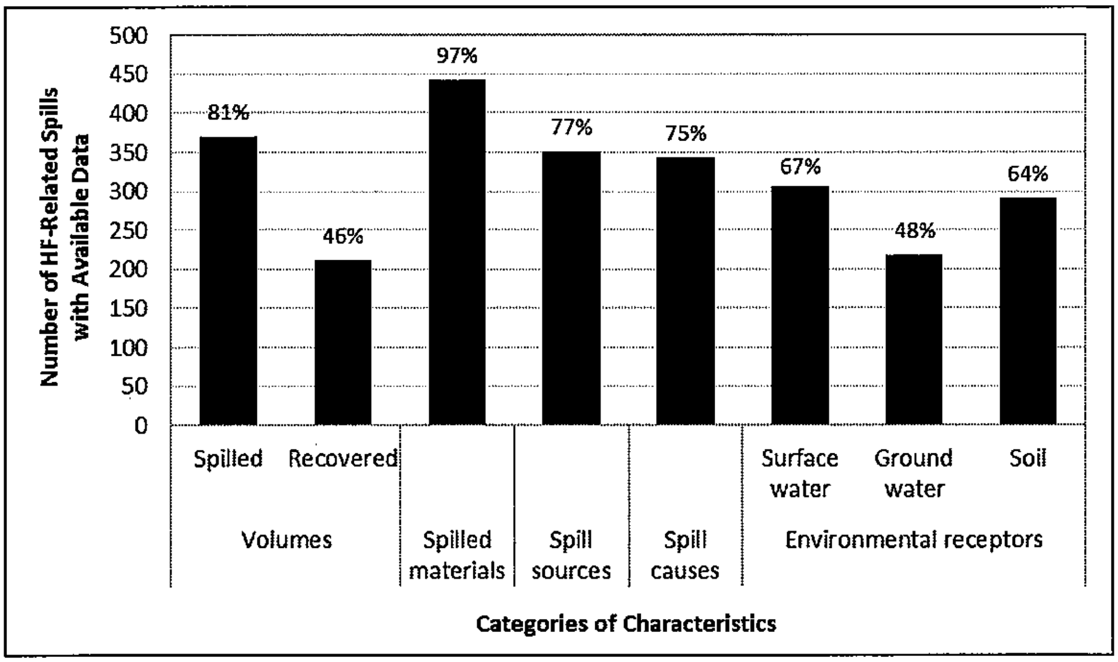
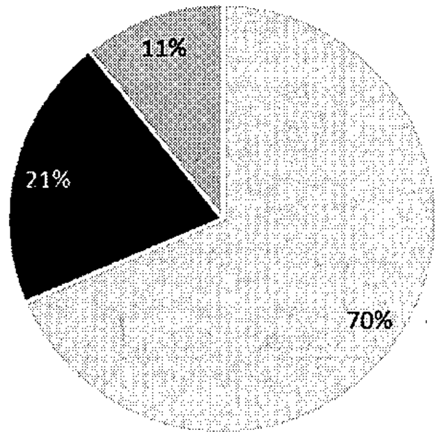


Figure 2. Availability of reported information in records from hydraulic fracturing (HF)-related spills for each spill characteristic assessed. The percent of the number of hydraulic fracturing-related spills (out of 457) is noted above each column.

4.1. Volumes Spilled

Spilled volumes were reported and categorized for 81 percent of the hydraulic fracturing-related spills (370 spills; Figure 2). Reported volumes per spill ranged from fewer than 5 gallons to over 1.3 million gallons, with a median volume per spill of 730 gallons. As shown in Figure 3, hydraulic fracturing-related spills were characterized by numerous low-volume spills and comparatively fewer high-volume incidents. Fifty-six percent of the hydraulic fracturing-related spills with reported spill volumes resulted in a release of 1,000 gallons or less. These smaller spills, the majority of which did not exceed 500 gallons (Figure 3 inset), released a total reported volume of



Fluid Fate	Total Reported Volume (gallons)
Unrecovered	1,600,000
Recovered	480,000
Unknown	250,000
Total Spilled	*2,300,000*

Figure 4. Percent distribution of fluid fate by total reported volume for hydraulic fracturing-related spills. Volumes spilled were reported for 370 hydraulic fracturing-related spills, and 211 spill records contained information on volumes recovered. "Unknown" volumes were determined from spill records in which the volume spilled was reported, but no information was included about volumes recovered. "Unrecovered" volumes were calculated from data provided in the spill records for volumes spilled and volumes recovered. In some cases, reported recovered volumes were larger than reported spilled volumes. Therefore, the sum of unrecovered, recovered, and unknown fluid fate volumes is greater than the total volume spilled.

in which a spilled volume was reported. The fate of approximately 250,000 gallons from these spills without recovery information was therefore unknown.

4.2. Spilled Materials

Materials spilled were identified and categorized for 97 percent of hydraulic fracturing-related spills (443 spills; Figure 2). The types of spilled materials reported in the state and industry data sources, along with definitions and examples, are shown in Table 3. Table 4 summarizes spilled materials by number of spills, total reported volume spilled, median reported volume per spill, and the 5th and 95th percentile reported volume per spill for each material type. The percent distribution of the number of hydraulic fracturing-related spills and the total reported volume spilled by material type are presented in Figure 5.

Table 4 and Figure 5 show that flowback and produced water was the most common type of fluid reported to have been spilled (48 percent of 464 spills of different materials). Flowback and produced water also accounted for the largest total volume of spilled material (85 percent), with approximately 2 million gallons reported to have been spilled. Much of the estimated total volume spilled of flowback and produced water was from 13 spills, each over 10,000 gallons and totaling approximately 1.7 million gallons. There were 88 reported spills of fracturing fluid, with a median reported volume per spill of 820 gallons and a total of approximately 140,000 gallons of fluid reported to have been spilled. The 34 spills of frac water involved some of the largest hydraulic fracturing-related spills, as evidenced by high median (1,800 gallons) and 95th percentile (11,000 gallons) reported volumes per spill.

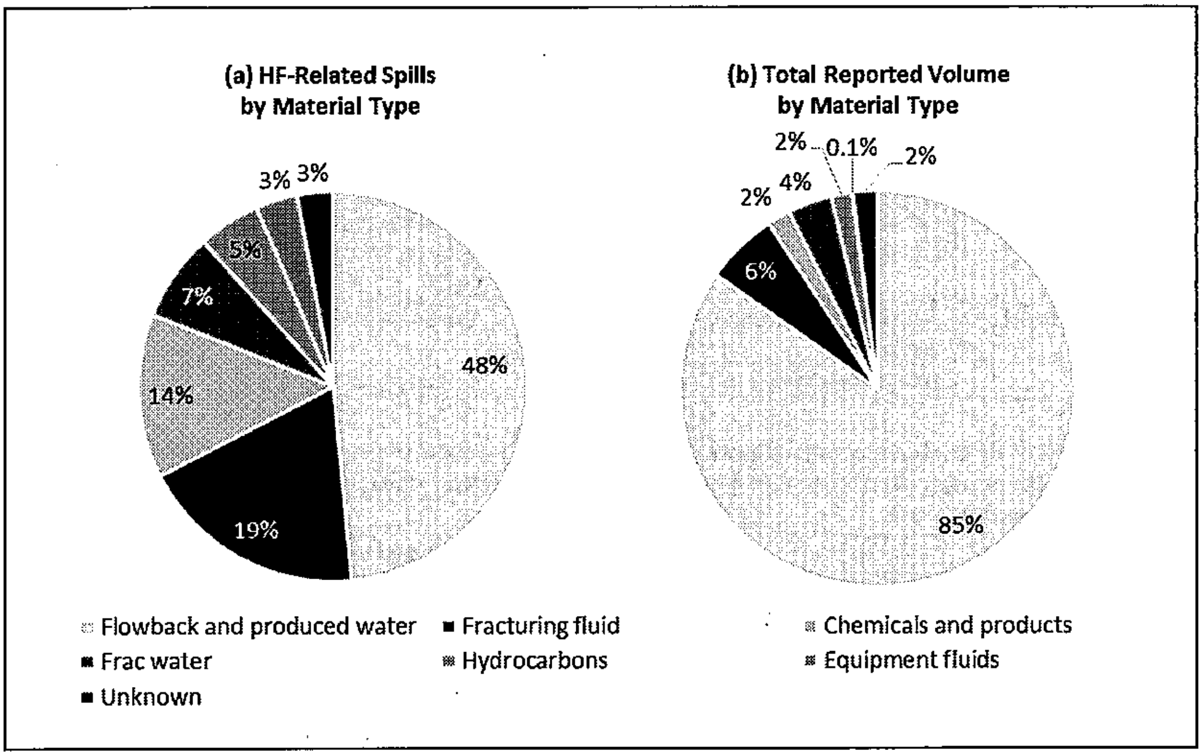


Figure 5. Summary of materials spilled by (a) number of hydraulic fracturing (HF)-related spills and (b) total reported volume spilled. There were six hydraulic fracturing-related spills in which more than one fluid was spilled. These spills were counted multiple times (once for each fluid spilled). Similarly, total volumes spilled were counted multiple times (once for each fluid spilled). Percentages do not sum to 100 percent due to rounding.

material was flowback and produced water (88 spills), with a median reported volume per spill of 420 gallons. The next most commonly reported spilled material (48 spills), when 1,000 gallons or less, were spilled were chemicals and products, with a median reported volume per spill of 200 gallons.

4.3. Spill Sources

The spill source was identified and categorized for 77 percent of all hydraulic fracturing-related spills (351 spills; Figure 2). Source types, definitions, and examples are shown in Table 5. Table 6 summarizes spill sources by number of spills, total reported volume spilled, median reported volume per spill, and the 5th and 95th percentile reported volumes per spill for each source type. Figure 6 presents percent distributions of the number of spills and the estimated total volume spilled by each source type.

Storage units, such as tanks or pits, were the most commonly reported source of spills (46 percent of 458 spills from different sources). The total volume reported to have been spilled from storage units was approximately 1.7 million gallons (75 percent of the total reported volume spilled for all hydraulic fracturing-related spills), with a median reported volume per spill of 840 gallons. Fewer spills were associated with wells or wellheads, but these spills had the greatest median and percentile reported spill volumes compared to all other sources, including those from storage containers.

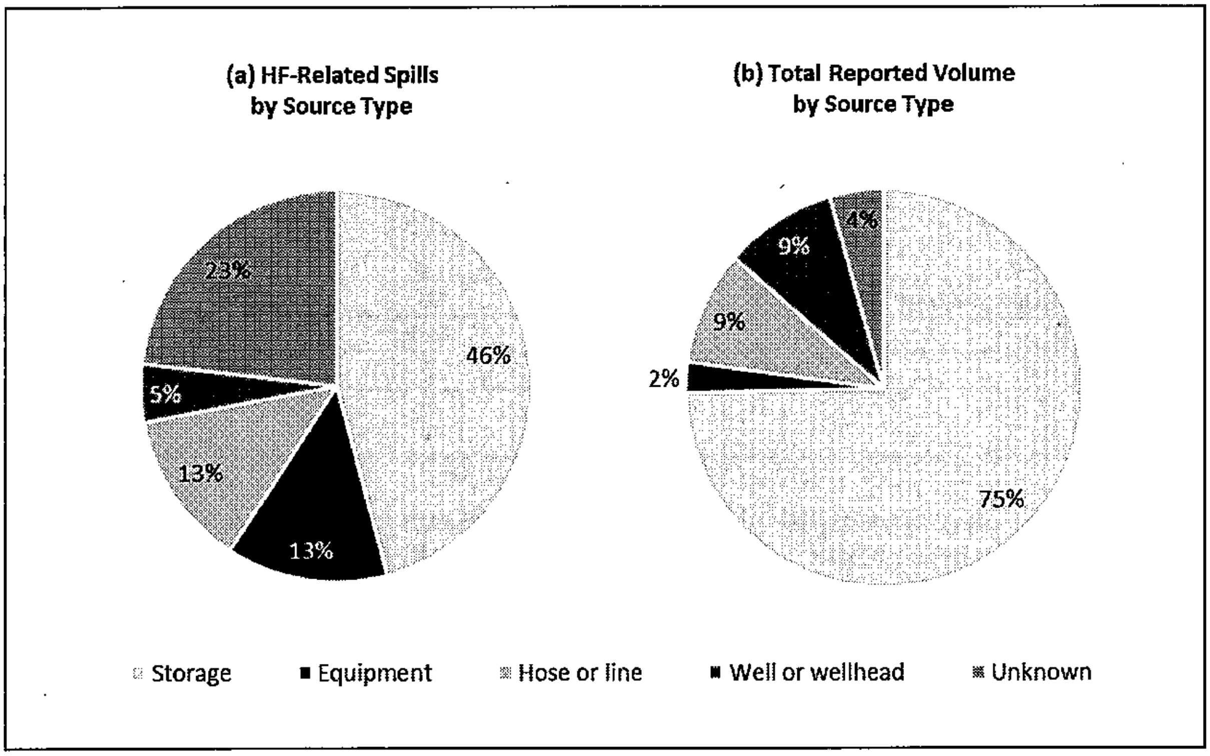


Figure 6. Summary of spill sources by (a) number of hydraulic fracturing (HF)-related spills and (b) total reported volume spilled. There was one spill in which more than one source was identified. This instance was counted multiple times (once for each source). Similarly, the total volume spilled for this spill was counted multiple times (once for each source). Percentages in graph (b) do not sum to 100 percent due to rounding.

Table 7. Definitions and examples of spill causes.

Cause Type	Definition	Examples
Human error	Human error as listed by the state or determined to be the root spill cause	Valve left open, miscommunication, failure to monitor or equalize tanks
Equipment failure	Equipment failure as listed by the state or determined to be the root spill cause	Blowout preventer failure, corrosion or washout, valve failed
Failure of container integrity	Holes, leaks, and seal failures in storage units	Hole, leak, seal failure
Other	Assorted causes of spills	Blowout, weather, vandalism, well communication
Unknown	Unknown or unspecified cause; not reported	Unknown, not specified, unanticipated flowback

Appendix B includes hydraulic fracturing-related spills that were caused by two well blowouts[13] and ten well communication events,[14] which were included in the "Other" or "Equipment failure" categories. Well blowouts and well communication events can both lead to high volume spills. The

[13] Line numbers 326 and 339 in Appendix B.

[14] Line numbers 163, 236, 265, 271, 286, 287, 375, 376, 377, and 380 in Appendix B.

volumes spilled due to weather spills ranged from 60 to 16,000 gallons per spill; these spills were usually caused by freezing conditions that led to frozen valves and ruptured lines.

Small volume hydraulic fracturing-related spills (1,000 gallons or less of fluid released) were most commonly caused by human error (78 spills). The median reported volume per spill from human error was 420 gallons. Sixty-eight spills were caused by equipment failure, which was the second most frequent cause of small volume spills. The median reported volume per spill due to equipment failure was 270 gallons.

4.5. Environmental Receptors

Environmental receptors are the environmental media reached by spilled fluids. Three types of environmental receptors were considered for this analysis: surface water, ground water, and soil. These environmental receptors are of particular interest when considering potential impacts to drinking water resources from hydraulic fracturing-related spills. Soil was included because spilled fluids may infiltrate soil and percolate into ground water (Bodvarsson et al., 2000; Schwarzenbach et al., 2002; US EPA, 1996). Surface and ground water resources could be currently used as drinking water resources or may provide drinking water in the future. The EPA did not determine whether any surface or ground water environmental receptors currently serve as drinking water resources.

Appendix B includes 411 spills (approximately 90 percent of the total number of hydraulic fracturing-related spills) for which information regarding whether or not the spilled fluid reached an environmental receptor was available. Information about whether or not spilled fluids reached any of these environmental receptors was not available for 46 spills. Figure 8 shows the number of hydraulic fracturing-related spills in which spilled fluids reached surface water, ground water, or soil. Also shown in Figure 8 is the number of times spilled fluids were reported as not reaching an environmental receptor or when it could not be determined if any environmental receptor was reached from the available data.

There were no spills in which spilled fluids were reported as not reaching any of the three environmental receptors. In 186 spills, spilled fluids were reported as not reaching surface or ground water. Of these 186 spills, spilled fluids were reported to have reached soil in 107 spills. It was unknown whether spilled fluids reached soil or were contained in the other 79 spills.

There were 300 hydraulic fracturing-related spills (approximately 65 percent of the total number of hydraulic fracturing-related spills) in which spilled fluids reached at least one environmental receptor; 24 of these reached multiple environmental receptors. Soil was the most commonly reported environmental receptor, with spilled fluids reaching soil in over half of all spills in Appendix B. The median reported volume per spill for these spills was 630 gallons (Table 9). Spilled fluids reached surface water in 32 hydraulic fracturing-related spills (approximately 7 percent of all hydraulic fracturing-related spills); the median reported volume per spill was 3,500 gallons. There was one spill in which spilled fluids reached ground water (0.2 percent of spills). The spill that

5. Results: Containment and Response

Fluid containment and spill response affect the path of spilled fluids and are important to understand when assessing the potential for impacts to drinking water resources. Approximately 25 percent of the spill records associated with hydraulic fracturing-related spills included information on containment systems, while approximately 60 percent described response activities. This section summarizes containment and response activities intended to prevent impacts to drinking water resources once a spill has occurred.

5.1. Containment

Containment systems are used to hold fluids or to stop the flow of spilled fluids. They can include primary, secondary, and emergency containment systems. Primary containment systems are the storage units, such as tanks or pits, in which fluids are intentionally kept. Pre-planned secondary containment systems, such as liners and berms, are installed before a spill occurs and are intended to contain spilled fluids until they can be cleaned up. Emergency containment systems are often temporary and are not in place before a spill occurs, but rather are implemented in response to a spill. The most common types of containment systems mentioned in the hydraulic fracturing-related spill records included pre-planned secondary or emergency systems such as berms, booms, dikes, liners, and pits.

Secondary containment systems surround primary containment systems and are generally intended to provide temporary containment of any spilled fluids until appropriate actions are taken to stop the spill and remove the fluid. Due to the limited information on pre-planned secondary containment in the hydraulic fracturing-related spill records, it was not possible to evaluate the extent to which the measures taken to contain spills were effective. In some cases, "effectiveness" appeared to be determined by whether the spilled fluid was contained on the site or within the pre-planned secondary containment unit. For example, a spill record from Pennsylvania noted that an unspecified volume of "frac fluid spilled before going downhole" and "no evidence of any fluid leaving containment was observed."[18] Another record from Wyoming was more specific: 1,260 gallons of produced water spilled around a tank and was contained in a berm. The spill record also noted that a "small portion soaked into [the] ground."[19] This indicated that the containment did not completely prevent spilled fluids from reaching an environmental receptor.

In at least two instances in Colorado, the pre-planned secondary containment systems appeared to be successful at both preventing fluid migration off-site and preventing spilled fluid from entering soil or water through the use of a liner. The first incident report, in 2010, described a tank overflow resulting in the release of 420 gallons of flowback fluid. The report stated:

[18] Line number 360 in Appendix B.

[19] Line number 388 in Appendix B.

flowback and produced water leaked from a failed weld on a flowback tank.[23] Consequently, "a dike and berm [were] constructed around [the flowback] tank" to contain the release. Similar to secondary containment reports, it was often unclear if emergency containments systems successfully prevented an impact to environmental media.

Absorbent materials were reported to have been used to contain spilled fluids. In general, it appears that absorbent materials were used when the estimated spill volumes were relatively small (10 to 200 gallons) and the spilled materials were individual chemicals or chemical products (e.g., scale inhibitors) rather than wastewater (i.e., flowback and produced water).

5.2. Response

Approximately 60 percent of spill records for spills identified as having been associated with hydraulic fracturing contained information about company responses, state responses, or both. The summary below focuses on the actions taken to clean up spilled fluids, which ranged from immediate actions to stop the spill and contain the spilled fluid to longer term actions to remediate the affected area.

The immediate responses to spills were varied, as shown in Table 11. In general, it was reported that actions were first taken to stop the spill (e.g., shut down operations, adjust equipment, or drain a leaking container) and then to contain the spilled fluid (e.g., construct emergency containment). In some situations, spills were discovered after fluids had been released from the primary containment unit (e.g., a tank). In these cases, it appeared that the focus of the immediate response was to contain the spilled fluid, if possible.

After a spill is stopped and contained, the response shifts to remediation. For this analysis, "remediation" was considered to be any action taken in response to the spill, including removal of contaminated material. The most commonly reported remediation activity, mentioned in approximately half of the hydraulic fracturing-related spill records, was removal of either the spilled fluid and/or affected media (typically soil). In the spill records, removal included excavation of contaminated soil and use of absorbent material and/or vacuum trucks to remove the spilled fluid. Removal activities were found to occur in various combinations. For example, a spill of approximately 4,200 gallons of acid was cleaned up by first spreading soda ash to neutralize the acid and then removing the affected soil.[24]

In general, a higher percentage of fluid volume was recovered for spills of up to 1,000 gallons. At the other extreme, the report of the spill of 1.3 million gallons indicated that no fluids were recovered. In some cases the volume recovered exceeded the volume spilled, because the spilled fluid mixed with water or soil due to precipitation spills (i.e., rain or snow).

[23] Line number 49 in Appendix B.

[24] Line number 258 in Appendix B.

during oil and gas operations and found that the spilled fluid volumes were predominantly below 500 gallons for oil spills and 1,700 gallons for saltwater spills, with few releases exceeding 21,000 gallons. A recent study of spills reported to the Colorado Oil and Gas Conservation Commission found that the most common spill volume was between 462 and 2,100 gallons (11 to 55 barrels), followed by spills between 84 and 420 gallons (2 to 10 barrels) (Colorado Department of Natural Resources, 2014).

This report describes hydraulic fracturing-related spills in terms of the following characteristics: volumes and materials spilled, sources and causes of spills, and environmental receptors. As discussed below, combinations of spill characteristics (e.g., materials spilled and source) can be used to identify common spill scenarios.

Among the entire dataset of 457 hydraulic fracturing-related spills, the most common spill scenario found was spills of flowback and produced water due to human error (19 percent), with a median reported volume per spill of 1,000 gallons. Fourteen percent of all spills were of flowback and produced water due to human error at storage units, with a median reported volume per spill of 840 gallons. An example of this spill scenario is the 8,400 gallons of flowback reported to have spilled when a valve on a flowback tank was accidentally left open.[27]

Spill records from 370 hydraulic fracturing-related spills contained information on volumes of fluid spilled. Fifty-six percent of these spills reported spilled volumes of 1,000 gallons or less, which suggests that most reported hydraulic fracturing-related spills were relatively low volume. Spill scenarios identified for these low-volume spills were similar to spill scenarios observed for the entire dataset. Eighteen percent of low-volume spills were spills of flowback and produced water due to human error, with a median reported volume per spill of 460 gallons. Fourteen percent of low-volume spills were spills of flowback and produced water due to human error at storage units, with an estimated median reported volume per spill of 550 gallons.

Large volume spills from well blowouts and well communication events have recently been reported by the media (Atkin, 2014; Vaidyanathan, 2013). Similar types of spills were identified as part of this study. For example, a spill in Oklahoma occurred when "fracing story #5 communicated with story #2," leading to over 13,000 gallons of oil being released.[28] In another instance, failure of blowout prevention equipment caused a well in Pennsylvania to discharge natural gas and flowback for 18 hours before it was contained.[29] These types of spills represented a small proportion of the hydraulic fracturing-related spills in Appendix B: two spills were caused by well blowouts[30] and ten spills were caused by well communication.[31]

Large and small volumes of spilled fluids were reported to have reached at least one environmental receptor (i.e., surface water, ground water, or soil) in 300 spills. In 24 instances, spilled fluids were reported to have reached more than one environmental receptor. Soil was the most predominant

[27] Line number 390 in Appendix B.

[28] Line number 286 in Appendix B.

[29] Line number 326 in Appendix B.

[30] Line numbers 326 and 339 in Appendix B.

[31] Line numbers 163, 236, 265, 271, 286, 287, 375, 376, 377, and 380 in Appendix B.

7. Conclusions

This report presents the results of a broad review of state and industry spill data from 457 hydraulic fracturing-related spills. Data from these spills were used to characterize volumes and materials spilled, spill sources and causes, and environmental receptors. There were several key findings. Spills related to hydraulic fracturing were most often characterized by numerous, low volume events (up to 1,000 gallons) and relatively few high volume events (greater than 20,000 gallons). The most common material spilled was flowback and produced water, and the most common source of spills was storage units. More spills were caused by human error than any other cause. Over half of the spills associated with hydraulic fracturing reached an environmental receptor, with 33 instances of spilled fluids reaching surface or ground water resources. These results, as well as other information on spill characteristics and containment and response activities, provide important insights into the nature of hydraulic fracturing-related spills in several key states with hydraulic fracturing.

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A.2. Spilled Materials

Spilled materials were assigned to the broad categories listed in Table 3. Some materials identified in the spill reports were not unique to hydraulic fracturing (e.g., produced water). In these cases, spills were only added to Appendix B if other hydraulic fracturing-specific terminology (e.g., frac, hydraulic fracturing) was identified in the spill report.

A.3. Spill Sources

Spill sources were assigned to the broad categories listed in Table 5 based on where spilled fluids originated. In general, spills must have occurred on a well pad during the hydraulic fracturing treatment or during flowback to be included in Appendix B.

A.4. Spill Causes

Spill causes were assigned to the broad categories listed in Table 7.

A.5. Environmental Receptors

Environmental receptors included soil, surface water, and ground water. Table A2 summarizes the categories developed for this analysis and their descriptions. A spill could be assigned to more than one category if it reached multiple environmental receptors.

Table A2. Categorization method for environmental receptors.

Category	Description
Surface Water	Surface water (e.g., creek, lake, pond, river, wetland)
Ground Water	Spill report specifically indicated ground water was reached
Soil	References to soil (e.g., crops, ditch, forest, pasture, ground, vegetation)
Unknown	Unspecified whether fluids reached an environmental receptor

When spilled materials were reported to have reached the well pad, an "unknown" environmental receptor was assigned, because it was often unclear whether the well pad was lined or not. A lined well pad may have prevented fluids from reaching soil, but an unlined well pad may not have prevented fluids from leaching into soil and possibly ground water. Additionally, secondary containment measures did not exclude the possibility of fluids reaching environmental receptors, and in cases where the secondary containment was earthen, soil was identified as the environmental receptor.

When surface water was reported as the environmental receptor, the specific type of surface water body (e.g., stream, river, wetland, pond) was identified, if sufficient information was provided. Dry ditches and drainage were not considered water bodies, because they were constructed for erosion and sediment control during site development. Standing water, or water collected in on-site pools, was considered a type of surface water receptor, because spilled materials mixed with these standing waters required site removal and/or treatment comparable to other surface water receptors.

Glossary

Aquifer: An underground geological formation, or group of formations, containing water. A source of ground water for wells and springs. (ref 5)

Blowout: An uncontrolled flow of formation fluids from a well. (ref 4)

Blowout preventer: A large valve at the top of a well that may be closed if the drilling crew loses control of formation fluids. (ref 4)

Condensate: A natural gas liquid with lower vapor pressure than natural gasoline or liquefied petroleum gas. It is mainly composed of propane, butane, pentane, and heavier hydrocarbon fractions. (ref 4)

Drinking water resource: Any body of water, ground or surface, that could currently, or in the future, serve as a source of drinking water for public or private water supplies. (ref 6)

Flowback: After the hydraulic fracturing procedure is completed and pressure is released, the direction of fluid flow reverses, and fluids flow up the wellbore to the surface. The fluids that return to the surface are commonly referred to as "flowback." (ref 2)

Formation: A geological formation is a body of earth material with distinctive and characteristic properties and a degree of homogeneity in its physical properties. (ref 5)

Ground water: Water found below the surface of the land, usually in porous rock formations. Ground water is the source of water found in wells and springs and is frequently used for drinking. (ref 5)

Hydraulic fracturing: A stimulation technique used to increase production of oil and gas. Hydraulic fracturing involves the injection of fluids under pressures great enough to fracture the oil and gas production formations. (ref 6)

Hydraulic fracturing fluid: Specially engineered fluids that generally contain water, proppants, and chemical additives. Hydraulic fracturing fluids are pumped under high pressure into the well to create and hold open fractures in the formation. (ref 3)

Natural gas: A naturally occurring mixture of hydrocarbon and non-hydrocarbon gases that is highly compressible and expansible. Methane is the chief constituent of most natural gas, with lesser amounts of ethane, propane, butane, and pentane. (ref 4)

Produced water: Formation fluids, and possibly fracturing fluids, that are produced from the hydrocarbon-bearing formation. Sometimes the term produced water is used synonymously with flowback.

Proppant: Sized particles (e.g., sand) mixed with fracturing fluid to hold fractures open after a hydraulic fracturing treatment. (ref 4)

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