Executive Summary

> A USDW is defined as an aquifer or a portion of an aquifer that:
>
> A. 1. *Supplies any public water system; or*
>   2. *Contains sufficient quantity of groundwater to supply a public water system; and*
>   i. *currently supplies drinking water for human consumption; or*
>   ii. *contains fewer than 10,000 milligrams per liter (mg/L) total dissolved solids (TDS); and*
>
> B. *Is not an exempted aquifer.*
>
> ***NOTE****:* Although aquifers with greater than 500 mg/L TDS are rarely used for drinking water supplies without treatment, the Agency believes that protecting waters with less than 10,000 mg/L TDS will ensure an adequate supply for present and future generations.

The U.S. Environmental Protection Agency (EPA, or the Agency) conducted a study that assesses the potential for contamination of underground sources of drinking water (USDWs) from the injection of hydraulic fracturing fluids into coalbed methane (CBM) wells. To increase the effectiveness and efficiency of the study, EPA has taken a phased approach. Apart from using real world observations and gathering empirical data, EPA also evaluated the theoretical potential for hydraulic fracturing to affect USDWs. Based on the information collected and reviewed, EPA has concluded that the injection of hydraulic fracturing fluids into CBM wells poses little or no threat to USDWs and does not justify additional study at this time. EPA's decision is consistent with the process outlined in the April, 2001 Final Study Design, which is described in Chapter 2 of this report.

The first phase of the study, documented in this report, is a fact-finding effort based primarily on existing literature to identify and assess the potential threat to USDWs posed by the injection of hydraulic fracturing fluids into CBM wells. EPA evaluated that potential based on two possible mechanisms. The first mechanism was the direct injection of fracturing fluids into a USDW in which the coal is located, or injection of fracturing fluids into a coal seam that is already in hydraulic communication with a USDW (e.g., through a natural fracture system). The second mechanism was the creation of a hydraulic connection between the coalbed formation and an adjacent USDW.

EPA also reviewed incidents of drinking water well contamination believed to be associated with hydraulic fracturing and found no confirmed cases that are linked to fracturing fluid injection into CBM wells or subsequent underground movement of fracturing fluids. Although thousands of CBM wells are fractured annually, EPA did not find confirmed evidence that drinking water wells have been contaminated by hydraulic fracturing fluid injection into CBM wells.

EPA has determined that in some cases, constituents of potential concern (section ES-6) are injected directly into USDWs during the course of normal fracturing operations. The use of diesel fuel in fracturing fluids introduces benzene, toluene, ethylbenzene, and xylenes (BTEX) into USDWs. BTEX compounds are regulated under the Safe Drinking Water Act (SDWA).

Given the concerns associated with the use of diesel fuel and the introduction of BTEX constituents into USDWs, EPA recently entered into a Memorandum of Agreement (MOA) with three major service companies to voluntarily eliminate diesel fuel from hydraulic fracturing fluids that are injected directly into USDWs for CBM production (USEPA, 2003). Industry representatives estimate that these three companies perform approximately 95 percent of the hydraulic fracturing projects in the United States. These companies signed the MOA on December 15, 2003 and have indicated to EPA that they no longer use diesel fuel as a hydraulic fracturing fluid additive when injecting into USDWs.

ES-1 How Does CBM Play a Role in the Nation's Energy Demands?

CBM production began as a safety measure in underground coalmines to reduce the explosion hazard posed by methane gas (Elder and Deul, 1974). In 1980, the U.S. Congress enacted a tax credit for non-conventional fuels production, including CBM production, as part of the Crude Oil Windfall Profit Act. In 1984, there were very few CBM wells in the U.S.; by 1990, there were almost 8,000 CBM wells (Pashin and Hinkle, 1997). In 1996, CBM production in 12 states totaled about 1,252 billion cubic feet, accounting for approximately 7 percent of U.S. gas production (U.S. Department of Energy, 1999). At the end of 2000, CBM production from 13 states totaled 1.353 trillion cubic feet, an increase of 156 percent from 1992. During 2000, a total of 13,973 CBM wells were in production (GTI, 2001; EPA Regional Offices, 2001). According to the U.S. Department of Energy, natural gas demand is expected to increase at least 45 percent in the next 20 years (U.S. Department of Energy, 1999). The rate of CBM production is expected to increase in response to the growing demand.

In evaluating CBM production and hydraulic fracturing activities, EPA reviewed the geology of 11 major coal basins throughout the United States (Figure ES-1). The basins shown in red have the highest CBM production volumes. They are the Powder River Basin in Wyoming and Montana, the San Juan Basin in Colorado and New Mexico, and the Black Warrior Basin in Alabama. Hydraulic fracturing is or has been used to stimulate CBM wells in all basins, but it has not frequently been used in the Powder River, Sand Wash, or Pacific Coal Basins. Table ES-1 provides production statistics for 2000 and information on hydraulic fracturing activity for each of the 11 basins in 2000.

Figure ES-1. Major United States Coal Basins

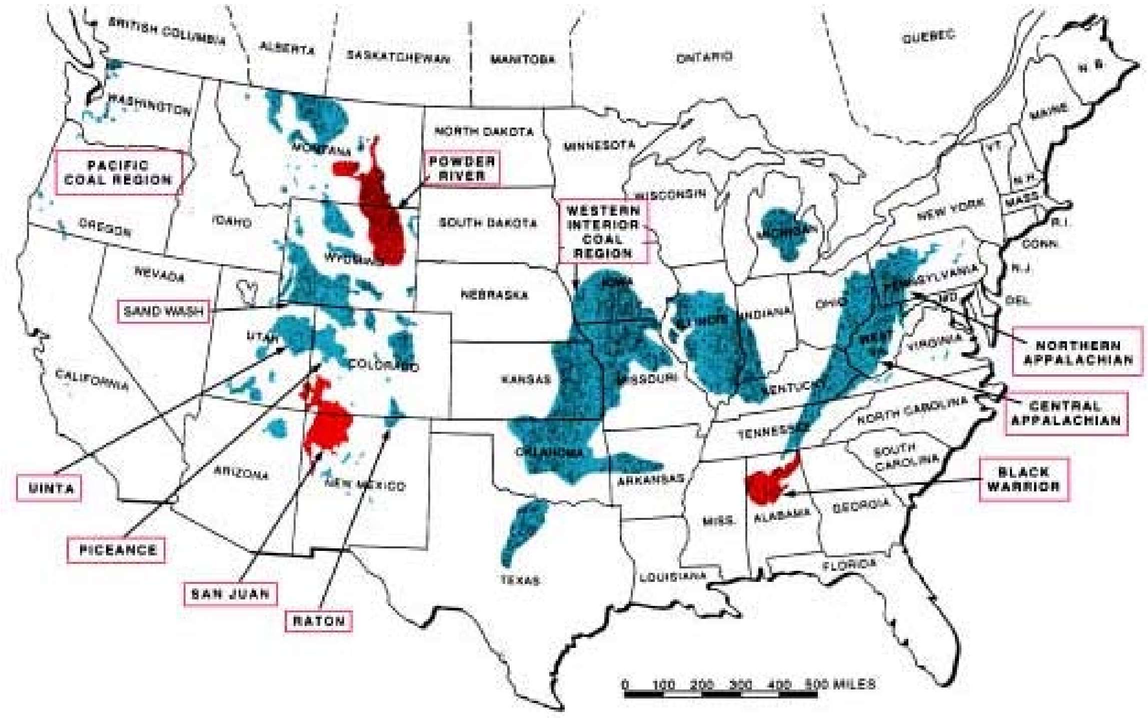


Table ES-1. Coal Basins Production Statistics and Activity Information in the U.S.

Basin	Number of CBM Producing Wells (Year 2000)*	Production of CBM in Billions of Cubic Feet (Year 2000)*	Does Hydraulic Fracturing Occur?
Powder River	4,200	147	Yes (but infrequently)
Black Warrior	3,086	112	Yes
San Juan	3,051	925	Yes
Central Appalachian	1,924	52.9	Yes
Raton Basin	614	30.8	Yes
Uinta	494	75.7	Yes
Western Interior	420	6.5	Yes
Northern Appalachian	134	1.41	Yes
Piceance	50	1.2	Yes
Pacific Coal	0	0	Yes (but infrequently)
Sand Wash	0	0	Yes (but infrequently)

* Data provided by the Gas Technology Institute and EPA Regional Offices. Production figures include CBM extracted using hydraulic fracturing and other processes.

ES-2 What Is Hydraulic Fracturing?

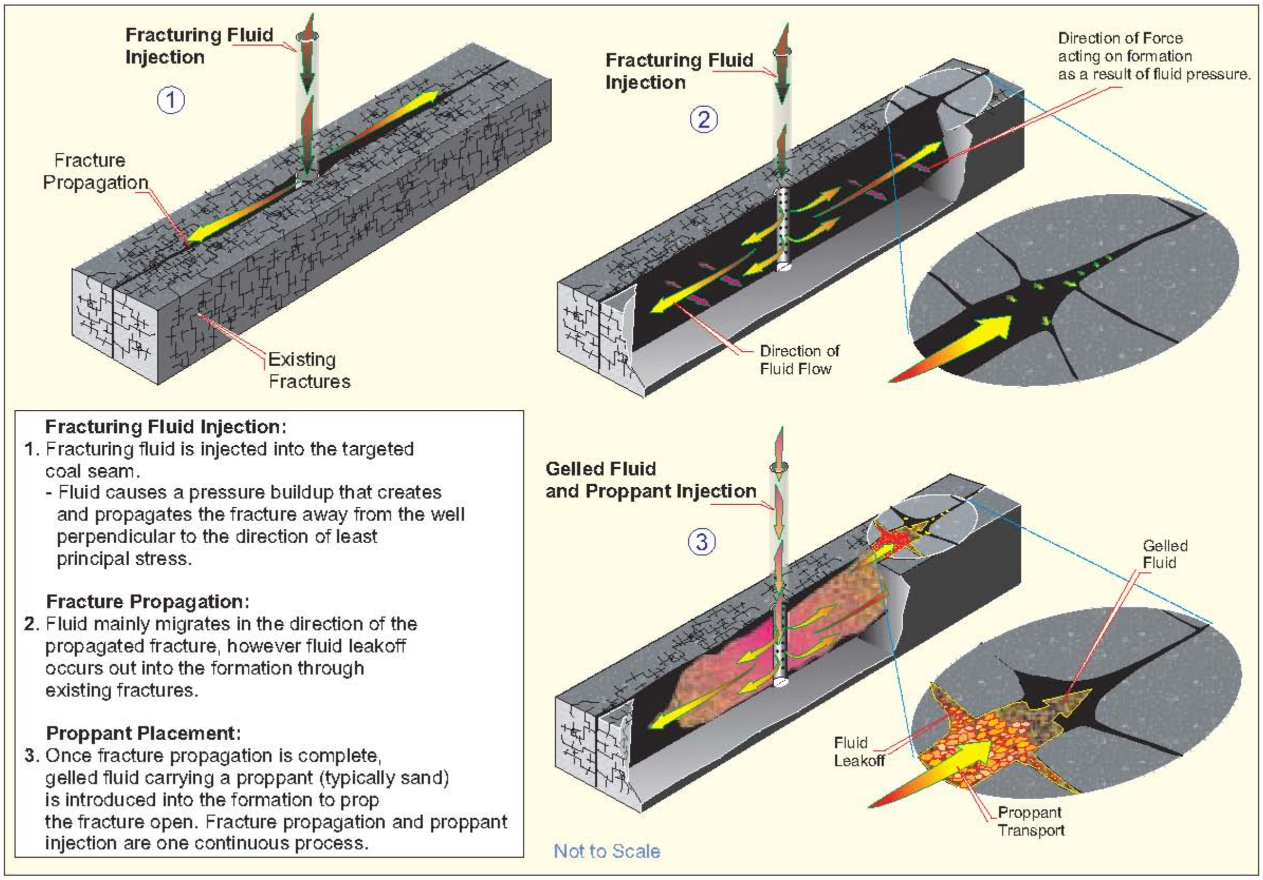
CBM gas is not structurally trapped in the natural fractures in coalbeds. Rather, most of the methane is adsorbed to the coal (Koenig, 1989; Winston, 1990; Close, 1993). To extract the CBM, a production well is drilled through the rock layers to intersect the coal seam that contains the CBM. Next, fractures are created or existing fractures are enlarged in the coal seam through which the CBM can be drawn to the well and pumped to the surface.

Figure ES-2 illustrates what occurs in the subsurface during a typical hydraulic fracturing event. This diagram shows the initial fracture creation, fracture propagation, proppant placement, and the subsequent fracturing fluid recovery/groundwater extraction stage of the CBM production process. The actual extraction of CBM generally begins after a period of fluid recovery/groundwater extraction. The hydraulically created fracture acts as a conduit in the rock or coal formation, allowing the CBM to flow more freely from the coal seams, through the fracture system, and to the production well where the gas is pumped to the surface.

To create or enlarge fractures, a thick fluid, typically water-based, is pumped into the coal seam at a gradually increasing rate and pressure. Eventually the coal seam is unable to accommodate the fracturing fluid as quickly as it is injected. When this occurs, the pressure is high enough that the coal fractures along existing weaknesses within the coal (steps 1 and 2 of Figure ES-1). Along with the fracturing fluids, sand (or some other propping agent or “proppant”) is pumped into the fracture so that the fracture remains “propped” open even after the high fracturing pressures have been released. The resulting proppant-containing fracture serves as a conduit through which fracturing fluids and groundwater can more easily be pumped from the coal seam (step 3 of Fig. ES-1).

To initiate CBM production, groundwater and some of the injected fracturing fluids are pumped out (or “produced” in the industry terminology) from the fracture system in the coal seam (step 4 of Figure ES-1). As pumping continues, the pressure eventually decreases enough so that methane desorbs from the coal, flows toward, and is extracted through the production well (step 5 of Figure ES-1). In contrast to conventional gas production, the amount of water extracted declines proportionally with increasing CBM production. In some basins, huge volumes of groundwater are extracted from the production well to facilitate the production of CBM.

Figure ES-2. A Graphical Representation of the Hydraulic Fracturing Process in Coalbed Methane Wells



Fracturing Fluid Injection:

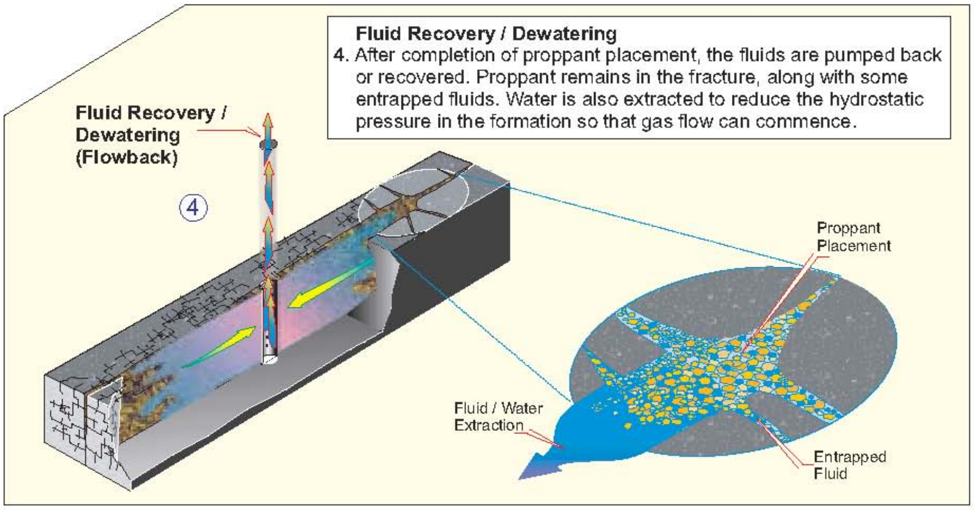
1. Fracturing fluid is injected into the targeted coal seam.
   - Fluid causes a pressure buildup that creates and propagates the fracture away from the well perpendicular to the direction of least principal stress.

Fracture Propagation:

2. Fluid mainly migrates in the direction of the propagated fracture, however fluid leakoff occurs out into the formation through existing fractures.

Proppant Placement:

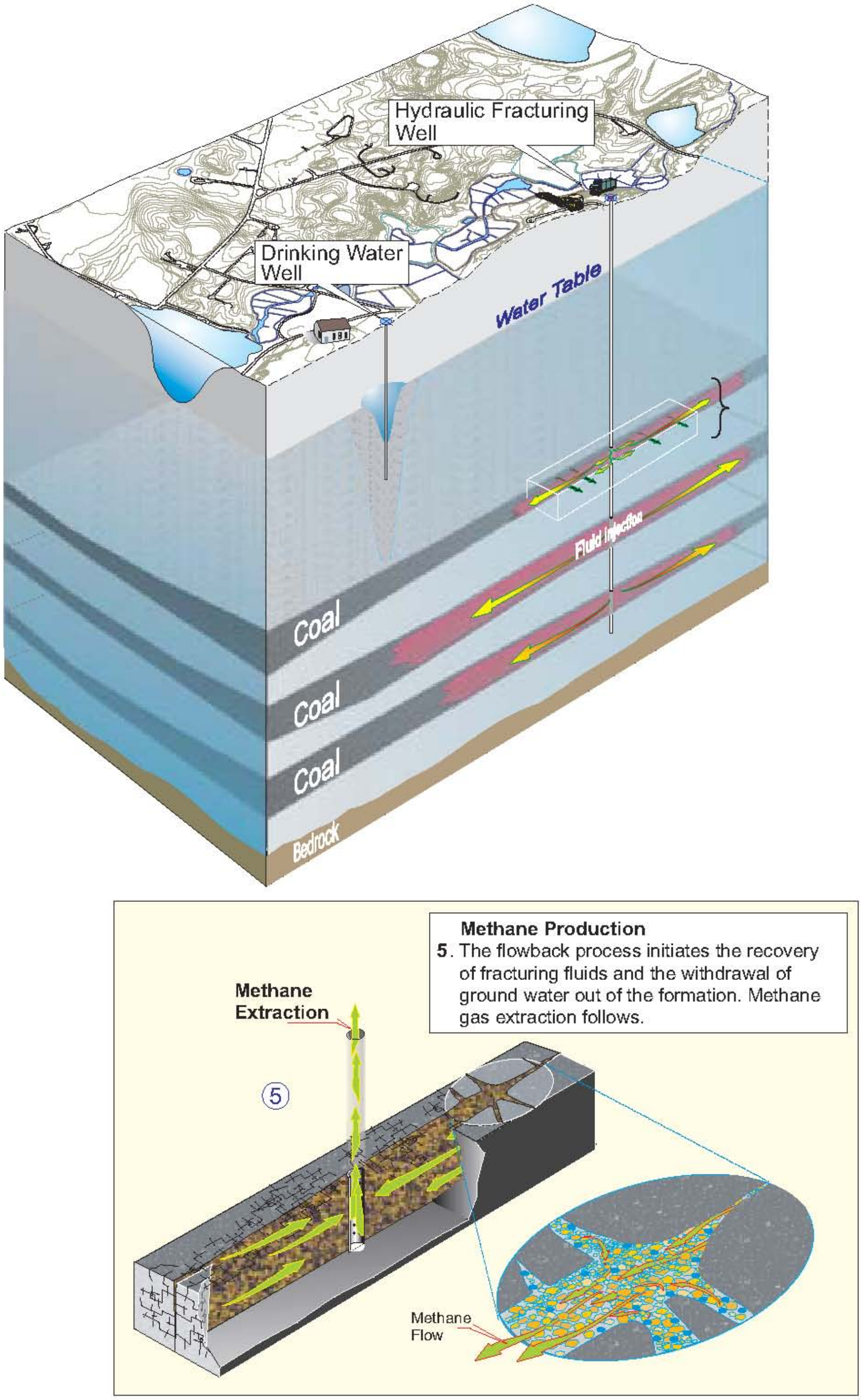
3. Once fracture propagation is complete, gelled fluid carrying a proppant (typically sand) is introduced into the formation to prop the fracture open. Fracture propagation and proppant injection are one continuous process.



Fluid Recovery / Dewatering

4. After completion of proppant placement, the fluids are pumped back or recovered. Proppant remains in the fracture, along with some entrapped fluids. Water is also extracted to reduce the hydrostatic pressure in the formation so that gas flow can commence.

Figure ES-2. A Graphical Representation of the Hydraulic Fracturing Process in Coalbed Methane Wells (Continued)



Methane Production

5. The flowback process initiates the recovery of fracturing fluids and the withdrawal of ground water out of the formation. Methane gas extraction follows.

ES-3 Why Did EPA Evaluate Hydraulic Fracturing?

SDWA requires EPA and EPA-authorized states to have effective programs to prevent underground injection of fluids from endangering USDWs (42 U.S.C. 300h et seq.). Underground injection is the subsurface emplacement of fluids through a well bore (42 U.S.C. 300h(d)(1)). Underground injection endangers drinking water sources if it may result in the presence of any contaminant in underground water which supplies or can reasonably be expected to supply any public water system, and if the presence of such a contaminant may result in such system's noncompliance with any national primary drinking water regulation (i.e., maximum contaminant levels (MCLs)) or may otherwise adversely affect the health of persons (42 U.S.C. 300h(d)(2)). SDWA's regulatory authority covers underground injection practices, but the Act does not grant authority for EPA to regulate oil and gas production.

In 1997, the Eleventh Circuit Court ruled, in *LEAF v. EPA* [LEAF v. EPA, 118F.3d 1467 (11th Circuit Court of Appeals, 1997)], that because hydraulic fracturing of coalbeds to produce methane is a form of underground injection, Alabama's EPA-approved Underground Injection Control (UIC) Program must effectively regulate this practice. In the wake of the Eleventh Circuit's decision, EPA decided to assess the potential for hydraulic fracturing of CBM wells to contaminate USDWs. EPA's decision to conduct this study was also based on concerns voiced by individuals who may be affected by CBM development, Congressional interest, and the need for additional information before EPA could make any further regulatory or policy decisions regarding hydraulic fracturing.

The Phase I study is tightly focused to address hydraulic fracturing of CBM wells and does not include other hydraulic fracturing practices (e.g., those for petroleum-based oil and gas production) because: (1) CBM wells tend to be shallower and closer to USDWs than conventional oil and gas production wells; (2) EPA has not heard concerns from citizens regarding any other type of hydraulic fracturing; and (3) the Eleventh Circuit litigation concerned hydraulic fracturing in connection with CBM production. The study also does not address potential impacts of non-injection related CBM production activities, such as impacts from groundwater removal or production water discharge. EPA did identify, as part of the fact-finding process, citizen concerns regarding groundwater removal and production water.

ES-4 What Was EPA's Project Approach?

Based on public input, EPA decided to carry out this study in discrete phases to better define its scope and to determine if additional study is needed after assessing the results of the preliminary phase(s). EPA designed the study to have three possible phases, narrowing the focus from general to more specific as findings warrant. This report describes the findings from Phase I of the study. The goal of EPA's hydraulic fracturing Phase I study was to assess the potential for contamination of USDWs due to the injection of hydraulic fracturing fluids into CBM wells and to determine based on these findings, whether further study is warranted.

Phase I is a fact-finding effort based primarily on existing literature. EPA reviewed water quality incidents potentially associated with CBM hydraulic fracturing, and evaluated the theoretical potential for CBM hydraulic fracturing to affect USDWs. EPA researched over 200 peer-reviewed publications, interviewed approximately 50 employees from industry and state or local government agencies, and communicated with approximately 40 citizens and groups who are concerned that CBM production affected their drinking water wells.

For the purposes of this study, EPA assessed USDW impacts by the presence or absence of documented drinking water well contamination cases caused by CBM hydraulic fracturing, clear and immediate contamination threats to drinking water wells from CBM hydraulic fracturing, and the potential for CBM hydraulic fracturing to result in USDW contamination based on two possible mechanisms as follows:

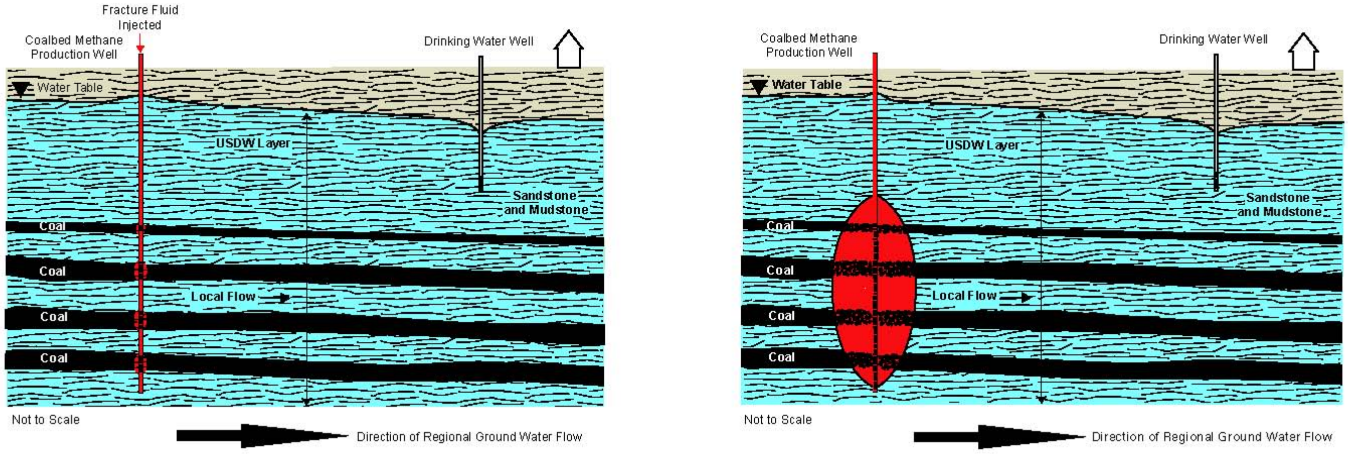
1. The direct injection of fracturing fluids into a USDW in which the coal is located (Figure ES-3), or injection of fracturing fluids into a coal seam that is already in hydraulic communication with a USDW (e.g., through a natural fracture system).

2. The creation of a hydraulic connection between the coalbed formation and an adjacent USDW (Figure ES-4).

Figure ES-3. Hypothetical Mechanisms - Direct Fluid Injection into a USDW (Where Coal Lies Within a USDW or USDWs)

Step 1:
Fracture Fluid is Injected into Coalbed Seams

Step 2:
Fracture Created



Step 3:
Some Fluid Stranded During Production

Step 4:
Stranded Fluid Migration Post-Production

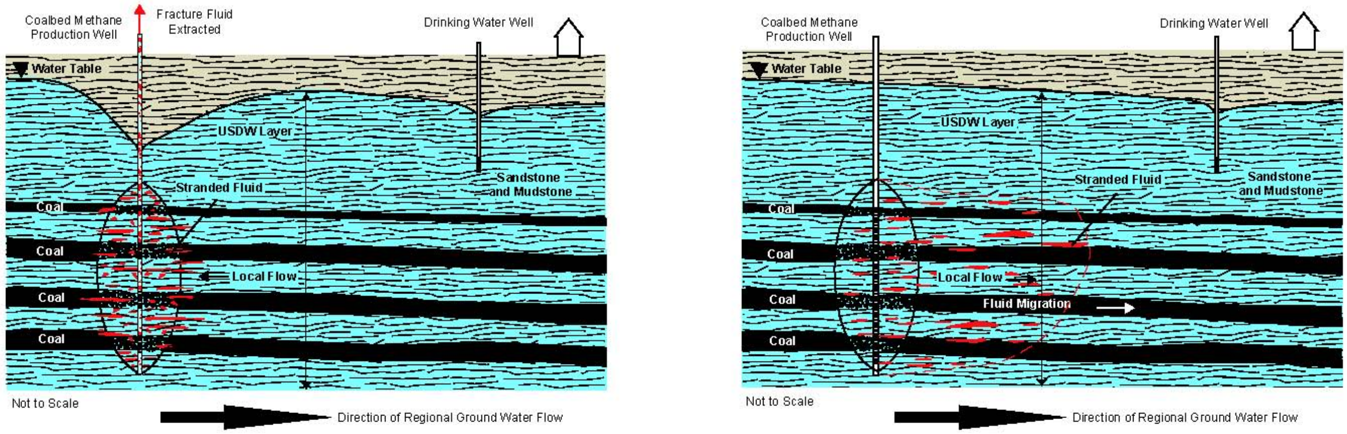
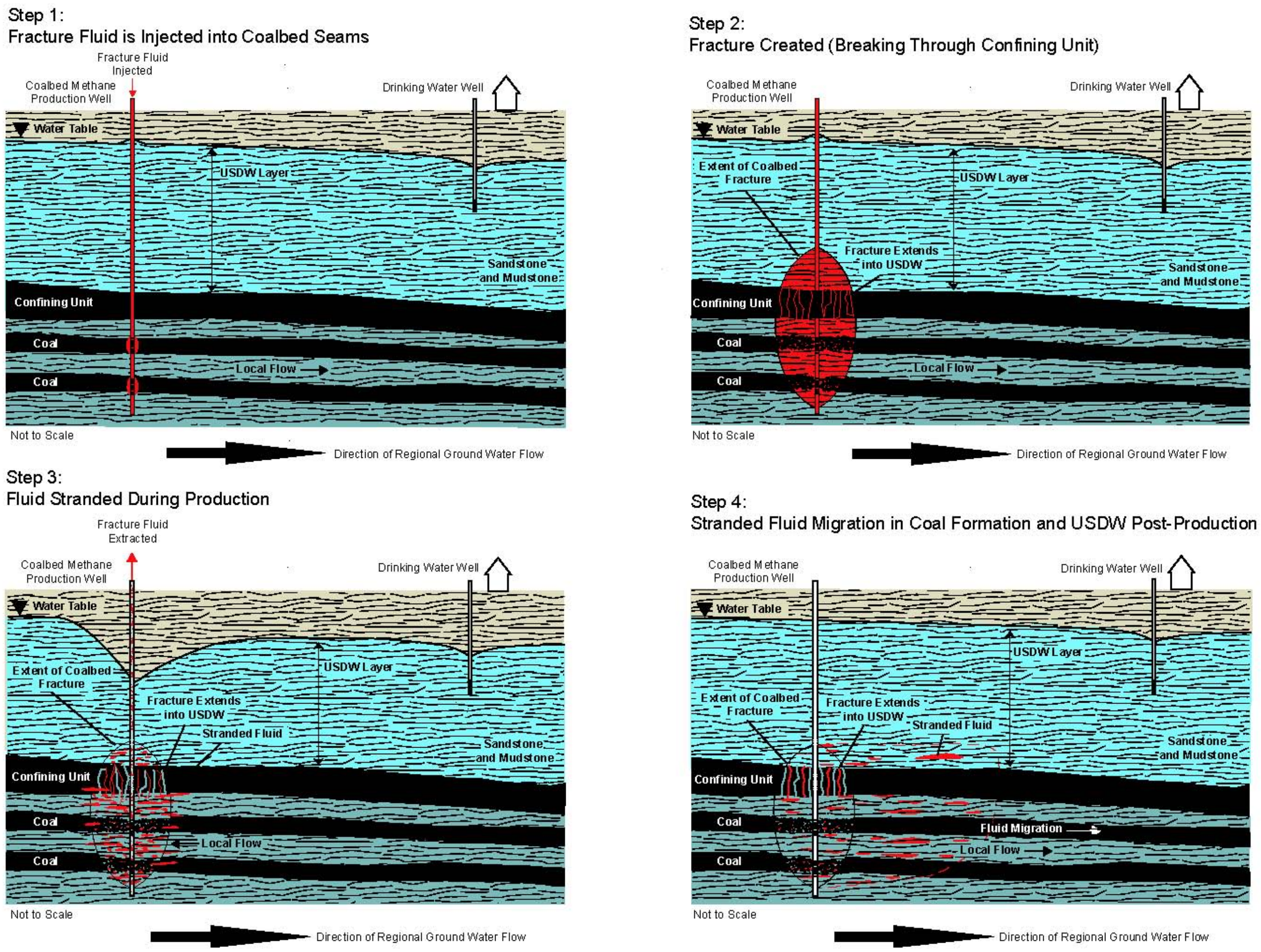


Figure ES-4. Hypothetical Mechanisms - Fracture Creates Connection to USDW



ES-5 How Do Fractures Grow?

In many CBM-producing regions, the target coalbeds occur within USDWs, and the fracturing process injects “stimulation” fluids directly into the USDWs. In other production regions, target coalbeds are adjacent to the USDWs (i.e., either higher or lower in the geologic section). Because shorter fractures are less likely to extend into a USDW or connect with natural fracture systems that may transport fluids to a USDW, the extent to which fractures propagate vertically influences whether hydraulic fracturing fluids could potentially affect USDWs.

The extent of the fractures is difficult to predict because it is controlled by the characteristics of the geologic formation (including the presence of natural fractures), the fracturing fluid used, the pumping pressure, and the depth at which the fracturing is being performed. Fracture behavior through coals, shales, and other geologic strata commonly present in coal zones depends on site-specific factors such as the relative thickness and in-situ stress differences between the target coal seam(s) and the surrounding geologic strata, as well as the presence of pre-existing natural fractures. Often, a high stress contrast between adjacent geologic strata results in a barrier to fracture propagation. An example of this would be where there is a geologic contact between a coalbed and an overlying, thick, higher-stress shale.

Another factor controlling fracture height can be the highly cleated nature of some coalbeds. In some cases, highly cleated coal seams will prevent fractures from growing vertically. When the fracturing fluid enters the coal seam, it is contained within the coal seam's dense system of cleats and the growth of the hydraulic fracture will be limited to the coal seam (see Appendix A).

Deep vertical fractures can propagate vertically to shallower depths and develop a horizontal component (Nielsen and Hansen, 1987, as cited in Appendix A: DOE, Hydraulic Fracturing). In the formation of these "T-fractures," the fracture tip may fill with coal fines or intercept a zone of stress contrast, causing the fracture to turn and develop horizontally, sometimes at the contact of the coalbed and an overlying formation. (Jones et al., 1987; Morales et al., 1990). For cases where hydraulically induced fractures penetrate into, or sometimes through, formations overlying coalbeds, they are most often attributed to the existence of pre-existing natural fractures or thinly inter-bedded layering.

ES-6 What Is in Hydraulic Fracturing Fluids?

Fracturing fluids consist primarily of water or inert foam of nitrogen or carbon dioxide. Other constituents can be added to fluids to improve their performance in optimizing fracture growth. Components of fracturing fluids are stored and mixed on-site. Figures ES-5 and ES-6 show fluids stored in tanks at CBM well locations.

During a hydraulic fracturing job, water and any other additives are pumped from the storage tanks to a manifold system placed on the production wells where they are mixed and then injected under high pressure into the coal formation (Figure ES-6). The hydraulic fracturing in CBM wells may require from 50,000 to 350,000 gallons of fracturing fluids, and from 75,000 to 320,000 pounds of sand as proppant (Holditch et al., 1988 and 1989; Jeu et al., 1988; Hinkel et al., 1991; Holditch, 1993; Palmer et al., 1991, 1993a, and 1993b). More typical injection volumes, based on average injection volume data provided by Halliburton for six basins, indicate a maximum average injection volume of 150,000 gallons of fracturing fluids per well, with a median average injection volume of 57,500 gallons per well (Halliburton, Inc., 2003).

Figure ES-5. Water used for the fracturing fluid is stored on-site in large, upright storage tanks and in truck-mounted tanks.

EPA reviewed material safety data sheets to determine the types of additives that may be present in fracturing fluids. Water or nitrogen foam frequently constitutes the solute in fracturing fluids used for CBM stimulation. Other components of fracturing fluids contain benign ingredients, but in some cases, there are additives with constituents of potential concern. Because much more gel can be dissolved in diesel fuel as compared to water, the use of diesel fuel increases the efficiency in transporting proppant in the fracturing fluids. Diesel fuel is the additive of greatest concern because it introduces BTEX compounds, which are regulated by SDWA.

A thorough discussion of fracturing fluid components and fluid movement is presented in Chapter 4.

Figure ES-6. The fracturing fluids, additives, and proppant are pumped from the storage tanks to a manifold system placed on the wellhead where they are mixed just prior to injection.

ES-7 Are Coalbeds Located within USDWs?

EPA reviewed information on 11 major coal basins to determine if coalbeds are co-located with USDWs and to understand the CBM activity in the area. If coalbeds are located within USDWs, then any fracturing fluids injected into coalbeds have the potential to contaminate the USDW. As described previously, a USDW is not necessarily currently used for drinking water and may contain groundwater unsuitable for drinking without treatment. EPA found that 10 of the 11 basins may lie, at least in part, within USDWs. Table ES-2 identifies coalbed basin locations in relation to USDWs and summarizes evidence used as the basis for the conclusions.

ES-8 Did EPA Find Any Cases of Contaminated Drinking Water Wells Caused by Hydraulic Fracturing in CBM Wells?

EPA did not find confirmed evidence that drinking water wells have been contaminated by hydraulic fracturing fluid injection into CBM wells. EPA reviewed studies and follow-up investigations conducted by state agencies in response to citizen reports that CBM production resulted in water quality and quantity incidents. In addition, EPA received reports from concerned citizens in each area with significant CBM development. These complaints pertained to the following basins:

- San Juan Basin (Colorado and New Mexico);
- Powder River Basin (Wyoming and Montana);
- Black Warrior Basin (Alabama); and
- Central Appalachian Basin (Virginia and West Virginia).

Examples of concerns and claims raised by citizens include:

- Drinking water with strong, unpleasant taste and odor.
- Impacts on fish, and surrounding vegetation and wildlife.
- Loss of water in wells and aquifers, and discharged water creating artificial ponds and swamps not indigenous to region.

Water quantity complaints were the most predominant cause for complaint by private well owners. After reviewing data and incident reports provided by states, EPA sees no conclusive evidence that water quality degradation in USDWs is a direct result of injection of hydraulic fracturing fluids into CBM wells and subsequent underground movement of these fluids. Several other factors may contribute to groundwater problems, such as various aspects of resource development, naturally occurring conditions, population growth, and historical well-completion or abandonment practices. Many of the incidents that were reported (such as water loss and impacts on nearby flora and fauna from discharge of produced water) are beyond the authorities of EPA under SDWA and the scope of Phase I of this study.

Table ES-2. Evidence in Support of Coal-USDW Co-Location in U.S. Coal Basins

Basin	Are coalbeds found within USDWs?	Explanation and/or evidence
San Juan	Yes	A large area of the Fruitland system produces water containing less than 10,000 mg/L total dissolved solid (TDS), the water quality criterion for a USDW. Analyses taken from a selected coal well area (16 of 27 wells) show that produce water containing less than 10,000 mg/L TDS (Kaiser et al., 1994).
Black Warrior	Yes	Some portions of the Pottsville Formation contain waters that meet the quality criteria of less than 10,000 mg/L TDS for a USDW. According to the Alabama Oil and Gas Board, some waters in the Pottsville Formation do not meet the definition of a USDW and have TDS levels considerably higher than 10,000 mg/L (Alabama Oil and Gas Board, 2002). In the early 1990s, several authors reported fresh water production from coalbed wells at rates up to 30 gallons per minute (in Pashin et al., 1991; Ellard et al., 1992).
Piceance	Unlikely	The CBM producing Cameo Coal Zone and the lower aquifer system in the Green River Formation are more than 6,000 feet apart. The coal zone, lies at great depth, roughly 6,000 feet below the ground surface in a large portion of the basin (Tyler et al., 1998). A composite water quality sample taken from 4,637 to 5,430 feet deep within the Cameo Coal Zone in the Williams Fork Formation exhibited a TDS level of 15,500 mg/L (Graham, 2001). The produced water from CBM extraction in the Piceance Basin is of such low quality that it must be disposed of in evaporation ponds; re-injected into the formation from which it came; or re-injected at even greater depths (Tessin, 2001).
Uinta	Likely	The water quality in the Ferron and Blackhawk varies greatly with location, each having TDS levels below and above 10,000 mg/l (Utah Department of Natural Resources, 2002)
Powder River	Yes	A report prepared by the United States Geological Survey (USGS) showed that samples of water co-produced from 47 CBM wells in the Powder River Basin all had TDS levels of less than 10,000 mg/L (Rice et al., 2000). The water produced by CBM wells in the Powder River Coal Field commonly meets drinking water standards. In fact, production waters such as these have been proposed as a separate or supplemental source for municipal drinking water in some areas (DeBruin et al., 2000).
Central Appalachian	Likely	Depths of coal groups are coincident with fresh water in at least two of the states within the overall basin (Kelafant et al., 1988; Wilson, 2001; Foster, 1980; Hopkins, 1966; USGS, 1973). Anecdotal information suggests that private wells in Virginia are screened within coal seams (Wilson 2001; VDMME, 2001).

Basin	Are coalbeds found within USDWs?	Explanation and/or evidence
Northern Appalachian	Yes	The depth of each coal group within the basin is coincident with the depths of USDWs (Kelafant et al., 1988; Platt, 2001; Foster, 1980; Hopkins, 1996; USGS, 1973; Sedam and Stein, 1970; USGS, 1971; Duigon, 1985). Water quality data from eight historic Northern Appalachian Coal Basin projects show TDS levels below 10,000 mg/L (Zebrowitz et al., 1991).
Western Interior:		
Arkoma	Yes (in Arkansas) Unlikely (in Oklahoma)	The depths of coalbeds within Arkansas are coincident with depths to fresh water (Andrews et al., 1998; Cordova, 1963; Friedman, 1982; Quarterly Review, 1993). Based on maps provided by the Oklahoma Corporation Commission (OCC) showing depths of the 10,000 mg/L TDS groundwater quality boundary in Oklahoma, the location of CBM wells and USDWs would most likely not coincide in that state. This is based on depths to coals typically greater than 1,000 feet (Andrews et al., 1998) and depths to the base of the USDW typically less than 900 feet (OCC Depth to Base of Treatable Water Map Series, 2001).
Cherokee	Yes	The depths of coalbeds in Kansas are coincident with depths to fresh water (Quarterly Review, 1993; Macfarlane, 2001; DASC, 2001a).
Forest City	Unlikely	The thinness of the aquifer suggests that there is significant separation from the deeper coalbeds within the basin (Bostic et al., 1993; DASC, 2001b; Condra and Reed, 1959; Flowerday et al., 1998).
Raton	Yes	Water quality results from CBM wells in the Raton Basin demonstrate TDS content of less than 10,000 mg/L. Nearly all wells surveyed show a TDS of less than 2,500 mg/L, and more than half had TDS of less than 1,000 mg/L (National Water Summary, 1984).
Sand Wash	Yes	Two gas companies produced water from coals that showed TDS levels below 10,000 mg/L. At Craig Dome in Moffat County, Cockrell Oil Corporation drilled 16 CBM wells. The wells yielded large volumes of fresh water with TDS <1,000 mg/L (Colorado Oil and Gas Commission, 2001). Fuelco was operating 11 wells along Cherokee arch. Water pumped from the wells contained 1,800 mg/L of TDS and was discharged to the ground under a National Pollution Discharge Elimination System (NPDES) permit (Quarterly Review, 1993).
Pacific and Central Coal Regions	Yes	Data from a 1984 study demonstrates the co-location of a coal seam and a USDW in Pierce County. Water quality information from four gas test wells indicates TDS levels between 1,330 and 1,660 mg/L, well below the 10,000 mg/L criterion (Dion, 1984). Wells in the basalts commonly yield 150 to 3,000 gallons per minute. TDSs levels in the water produced generally range from 250 to 500 mg/L (Dion, 1984).

ES-9 What Are EPA's Conclusions?

Based on the information collected and reviewed, EPA has determined that the injection of hydraulic fracturing fluids into CBM wells poses little or no threat to USDWs. Continued investigation under a Phase II study is not warranted at this time.

As proposed in the Final Study Design (April 2001), Phase I of the study was a limited–scope assessment in which EPA would:

- Gather existing information to review hydraulic fracturing processes, practices, and settings;
- Request public comment to identify incidents that have not been reported to EPA;
- Review reported incidents of groundwater contamination and any follow-up actions or investigations by other parties (state or local agencies, industry, academia, etc.); and,
- Make a determination regarding whether further investigation is needed, based on the analysis of information gathered through the Phase I effort.

EPA's approach for evaluating the potential threat to USDWs was an extensive information collection and review of empirical and theoretical data. EPA reviewed incidents of drinking water well contamination believed to be associated with hydraulic fracturing and found no confirmed cases that are linked to fracturing fluid injection into CBM wells or subsequent underground movement of fracturing fluids. Although thousands of CBM wells are fractured annually, EPA did not find confirmed evidence that drinking water wells have been contaminated by hydraulic fracturing fluid injection into CBM wells.

EPA also evaluated the theoretical potential for hydraulic fracturing to affect USDWs through one of two mechanisms:

1. Direct injection of fracturing fluids into a USDW in which the coal is located, or injection of fracturing fluids into a coal seam that is already in hydraulic communication with a USDW (e.g., through a natural fracture system).
2. Creation of a hydraulic connection between the coalbed formation and an adjacent USDW.

Regarding the question of injection of fracturing fluids directly into USDWs, EPA considered the nature of fracturing fluids and whether or not coal seams are co-located with USDWs. Potentially hazardous chemicals may be introduced into USDWs when fracturing fluids are used in operations targeting coal seams that lie within USDWs. In particular, diesel fuel contains BTEX compounds, which are regulated under SDWA.

However, the threat posed to USDWs by the introduction of some fracturing fluid constituents is reduced significantly by the removal of large quantities of groundwater (and injected fracturing fluids) soon after a well has been hydraulically fractured. In fact, CBM production is dependent on the removal of large quantities of groundwater. EPA believes that this groundwater production, combined with the mitigating effects of dilution and dispersion, adsorption, and potentially biodegradation, minimize the possibility that chemicals included in the fracturing fluids would adversely affect USDWs.

Because of the potential for diesel fuel to be introduced into USDWs, EPA requested, and the three major service companies agreed to, the elimination of diesel fuel from hydraulic fracturing fluids that are injected directly into USDWs for CBM production (USEPA, 2003). Industry representatives estimate that these three companies perform approximately 95 percent of the hydraulic fracturing projects in the United States.

In evaluating the second mechanism, EPA considered the possibility that hydraulic fracturing could cause the creation of a hydraulic connection to an adjacent USDW. The low permeability of relatively unfractured shale may help to protect USDWs from being affected by hydraulic fracturing fluids in some basins. If sufficiently thick and relatively unfractured shale is present, it may act as a barrier not only to fracture height growth, but also to fluid movement. Shale’s ability to act as a barrier to fracture height growth is primarily due to the stress contrast between the coalbed and the shale. Another factor controlling fracture height can be the highly cleated nature of some coalbeds. In some cases, when the fracturing fluid enters the coal seam, it is contained within the coal seam’s dense system of cleats and the growth of the hydraulic fracture will be limited to the coal seam (see Appendix A).

Some studies that allow direct observation of fractures (i.e., mined-through studies) indicate many fractures that penetrate into, or sometimes through, one or more formations overlying coalbeds can be attributed to the existence of pre-existing natural fractures. However, given the concentrations and flowback of injected fluids, and the mitigating effects of dilution and dispersion, adsorption, and potentially biodegradation, EPA does not believe that possible hydraulic connections under these circumstances represent a significant potential threat to USDWs.

It is important to note that states with primary enforcement authority (primacy) for their UIC Programs implement and enforce their regulations, and have the authority under SDWA to place additional controls on any injection activities that may threaten USDWs. States may also have additional authorities by which they can regulate hydraulic fracturing. With the expected increase in CBM production, the Agency is committed to working with states to monitor this issue.

REFERENCES

Alabama Oil and Gas Board. 2002. Public Comment OW-2001-0002-0029 to "Draft Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs." *Federal Register*. Vol. 63, No. 185. p. 33992, September 24, 2002.

Andrews, R.D., B.J. Cardott, and T. Storm. 1998. The Hartshorne Play in Southeastern Oklahoma: regional and detailed sandstone reservoir analysis and coalbed-methane resources. Oklahoma Geological Survey, Special Publication 98-7.

Bostic, J.L., L.L. Brady, M.R. Howes, R.R. Burchett, and B.S. Pierce. 1993. Investigation of the coal properties and the potential for coal-bed methane in the Forest City Basin. US Geological Survey, Open File Report 93-576.

Close, Jay. C. 1993. Natural Fractures in Coal; Chapter 5 of AAPG Studies in Geology 38, “Hydrocarbons from Coal”, pp. 119-133.

Colorado Oil and Gas Conservation Commission. 2001. http://www.oil-gas.state.co.us/

Condra, G.E. and E.C. Reed. 1959. The geological section of Nebraska. Nebraska Geological Survey Bulletin 14A, 1959.

Cordova, R.M. 1963. Reconnaissance of the ground-water resources of the Arkansas Valley Region, Arkansas. Contributions to the Hydrology of the United States, Geological Survey Water-Supply Paper 1669-BB, 1963.

DASC website. 2001a. Kansas elevation map. http://gisdasc.kgs.ukans.edu/dasc/kanview.html

DASC website. 2001b. Ozark Aquifer base map. http://gisdasc.kgs.ukans.edu/dasc/kanview.html

DeBruin, R.H., R.M. Lyman, R.W. Jones, and L.W. Cook. 2000. Information Pamphlet 7. Wyoming State Geological Survey.

Dion, N.P. 1984. Washington Ground-Water Resources. In National Water Summary, US Geological Survey Water-Supply Paper No. 2275, pp. 433-438.

Duigon, M.T. and M.J. Smigaj. 1985. First report on the hydrologic effects of underground coal mining in Southern Garrett County, Maryland, US Geological Survey Report of Investigations No. 41.

Elder, C.H. and M. Deul. 1974. Degasification of the Mary Lee coalbed near Oak Grove, Jefferson county, Alabama, by vertical borehole in advance of mining; US Bureau of Mines Report 7968.

Ellard, J.S., R.P. Roark, and W.B. Ayers. 1992. Geologic controls on coalbed methane production: an example from the Pottsville formation, Black Warrior Basin, Alabama USA. Symposium on Coalbed Methane Research and Development in Australia. James Cook University, p. 45-61.

Eleventh Circuit Court of Appeals, 1997. *LEAF v. EPA*, 118F.3d 1467.

Flowerday, C.F., R.D. Kuzelka, and D.T. Pederson, compilers. 1998. The Ground Water Atlas of Nebraska.

Foster, J.B. 1980. Fresh and saline ground-water map of West Virginia. US Geological Survey, West Virginia Geological and Economic Survey, Map WV-12.

Friedman, S.A. 1982. Determination of reserves of methane from coalbeds for use in rural communities in eastern Oklahoma. Oklahoma Geological Survey, Special Publication 82-3, 1982.

Gas Technology Institute (GTI). 2001. Personal communication with GTI staff.

Graham, G. 2001. Colorado Division of Water Resources, personal communication with staff.

Halliburton, Inc. 2003. Personal communication with Halliburton staff, fracturing fluid expert, Steve Almond. April 2003.

Hinkel, J.J., K.H. Nimerick, K. England, J.C. Norton, and M. Roy. 1991, Design and evaluation of stimulation and workover treatments in coal seam reservoirs; Proceedings 1991 Coalbed Methane Symposium, University of Alabama (Tuscaloosa), Tuscaloosa, p. 453-458.

Holditch, S.A., J.W. Ely, M.E. Semmelbeck, R.H. Carter, J. Hinkle, and R.G. Jeffrey. 1988. Enhanced recovery of coalbed methane through hydraulic fracturing; SPE Paper 18250, Proceedings 1988 SPE Annual Technical Conference and Exhibition (Production Operations and Engineering), p. 689.

Holditch, S.A., J.W. Ely, and R.H. Carter. 1989. Development of a coal seam fracture design manual; Proceedings, 1989 Coalbed Methane Symposium, Tuscaloosa, Alabama, pp. 299-320.

Holditch, S.A., 1993, Completion methods in coal-seam reservoirs; Journal of Petroleum Technology, v.45 n.3 (March 1993), pp. 270-276.

Hopkins, Herbert T. 1966. Fresh-saline water interface map of Kentucky. US Geological Survey, Kentucky Geological Survey, Series X.

Jeu, S.J., T.L. Logan, and R.A. McBane. 1988, Exploitation of deeply buried coalbed methane using different hydraulic fracturing techniques; SPE paper 18253, Proceedings 63rd Annual Technical Conference (Houston).

Jones, A.H., Bell, G.J., and Morales, R.H. 1987. Examination of potential mechanisms responsible for the high treatment pressures observed during stimulation of coalbed reservoirs; SPE Paper 16421, Proceedings, Department of Energy/SPE Symposium: Gas from Low Permeability Reservoirs, p. 317.

Kaiser, W.R., Swartz, T.E., and Hawkins, G.J. 1994. Hydrologic framework of the Fruitland formation, San Juan Basin. New Mexico Bureau of Mines and Minerals Bulletin 146: Coalbed methane in the upper Cretaceous Fruitland formation, San Juan Basin, New Mexico and Colorado, pp. 133-164.

Kelafant, J.R., D.E. Wicks, and V.A. Kuuskraa. March 1988. A geologic assessment of natural gas from coal seams in the Northern Appalachian Coal Basin. Topical Report – Final Geologic Report (September 1986 – September 1987).

Macfarlane, A. 2001. Kansas Geological Survey, personal communication.

Morales, R,H, McLennan, J.D., Jones, A.H., and Schraufnagel, R.A. 1990. Classification of treating pressures in coal fracturing; Proceedings of the 31st U.S. Symposium on Rock Mechanics, 31, pp. 687-694.

National Water Summary. 1984. Hydrologic events, selected water-quality trends, and ground-water resources. United States Geological Survey Water-Supply Paper No. 2275.

Nielsen, P. E. and Hanson, M. E. 1987. Analysis and Implications of Three Fracture Treatments in Coals at the USX Rock Creek Site Near Birmingham, Alabama, 1987 Coalbed Methane Symposium, Tuscaloosa, AL (Nov. 16-19, 1987).

OCC (Oklahoma Corporation Commission), Depth to Base of Treatable Water Map Series, 2001.

Palmer, I.D., N.S. King, and D.P. Sparks. 1991. The character of coal fracture treatments in Oak Grove field, Black Warrior basin, SPE paper no. 22914, Proceedings, 1991 Society of Petroleum Engineers annual technical conference and exhibition, pp.277-286.

Palmer, I.D., N.S. King, and D.P. Sparks. 1993a. The character of coal fracture treatments in the Oak Grove field, Black Warrior basin; In Situ, Journal of Coal Research, v.17 (3), pp. 273-309.

Palmer, I.D., S.W. Lambert, and J.L. Spitler. 1993b. Coalbed methane well completions and stimulations. Chapter 14 of AAPG Studies in Geology 38, pp. 303-341.

Pashin, J.C. and F. Hinkle. 1997. Coalbed Methane in Alabama. Geological Survey of Alabama Circular 192, 71pp.

Pashin, J.C., W.E. Ward, R.B. Winston, R.V. Chandler, D.E. Bolin, K.E. Richter, W.E. Osborne, and J.C. Sarnecki. 1991. Regional analysis of the Black Creek-Cobb coalbed methane target interval, Black Warrior Basin, Alabama. Alabama Geological Survey Bulletin 145, 127pp.

Platt, S. January, 2001. US EPA Region 3, personal communication.

Quarterly Review. 1993. Coalbed methane – state of the industry. Methane From Coal Seams Technology, August, 1993.

Rice, C.A., M.S. Ellis, and J.H. Bullock, Jr. 2000. Water co-produced with coalbed methane in the Powder River Basin, Wyoming: preliminary compositional data. US Geological Survey Open-File Report 00-372.

Sedam, A.C. and R.B. Stein. 1970. Saline ground-water resources of Ohio. Hydrologic Investigations Atlas HA-366, Department of the Interior, US Geological Survey.

Tessin, R. 2001. Colorado Oil and Gas Conservation Commission, personal communication.

Tyler, R., A.R. Scott, and W.R. Kaiser. 1998. Defining coalbed methane exploration fairways: An example from the Piceance Basin, Rocky Mountain Foreland. Western United States, Conference Document, March 23-25. http://georef.cos.com/cgi-bin/getRec?un=2001-012340

U.S. Department of Energy. 1999. Environmental Benefits of Advanced Oil and Gas Exploration and Production Technology, Office of Fossil Energy, p 8.

U.S. Environmental Protection Agency. 2001. Personal communication with EPA Regional staff.

US Environmental Protection Agency. 2003. A Memorandum of Agreement Between The United States Environmental Protection Agency And BJ Services Company, Halliburton Energy Services, Inc., and Schlumberger Technology Corporation Elimination of Diesel Fuel in Hydraulic Fracturing Fluids Injected into Underground Sources of Drinking Water During Hydraulic Fracturing of Coalbed Methane Wells, December 12, 2003. http://www.epa.gov/safewater/uic/pdfs/moa_uic_hyd-fract.pdf

United States Geological Survey (USGS). 1971. State of Ohio, 1:500,000 topographic map.

USGS. 1973. State of Kentucky, 1:500,000 topographic map. National Water Summary. 1984. Hydrologic events, selected water-quality trends, and ground-water resources. United States Geological Survey Water-Supply Paper No. 2275.

Utah Department of Natural Resources. 2002. Public Comment OW-2001-0002-0090 to "Draft Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs." *Federal Register*. Vol. 63, No. 185. p. 33992, September 24, 2002.

Virginia Department of Mines, Minerals, and Energy (VDMME). 2001. Personal communication with VDMME staff.

Wilson, R. February, 2001. Director, Virginia Division of Gas & Oil, Department of Mines, Minerals, and Energy, personal communication.

Winston, R.B. 1990. Vitrinite reflectance of Alabama's bituminous coal; Alabama Geological Survey Circular 139, 54 pp.

Zebrowitz, M.J., J.R. Kelafant, and C.M. Boyer. 1991. Reservoir characterization and production potential of the coal seams in Northern and Central Appalachian Basins. Proceedings of the 1991 Coalbed Methane Symposium, The University of Alabama/Tuscaloosa, May 13-16, 1991.