Water Management Associated with Hydraulic Fracturing

API GUIDANCE DOCUMENT HF2
FIRST EDITION, JUNE 2010

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Upstream Segment

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Executive Summary

Hydraulic fracturing has played an important role in the development of America's oil and gas resources for nearly 60 years. In the U.S., an estimated 35,000 wells are hydraulically fractured annually and it is estimated that over one million wells have been hydraulically fractured since the first well in the late 1940s. As production from conventional oil and gas fields continues to mature and the shift to non-conventional resources increases, the importance of hydraulic fracturing will also increase.

The purpose of this guidance document is to identify and describe many of the current industry best practices used to minimize environmental impacts associated with the acquisition, use, management, treatment, and disposal of water and other fluids associated with the process of hydraulic fracturing. This document focuses primarily on issues associated with the water used for purposes of hydraulic fracturing and does not address other water management issues and considerations associated with oil and gas exploration, drilling, and production. It complements two other API Documents; one (API Guidance Document HF1, *Hydraulic Fracturing Operations—Well Construction and Integrity Guidelines*, First Edition, October 2009) focused on groundwater protection related to drilling and hydraulic fracturing operations, [1] which specifically highlights recommended practices for well construction and integrity of hydraulically fractured wells, and the second (API Guidance Document HF3, *Surface Environmental Considerations Associated with Hydraulic Fracturing*, publication pending, but expected in 2nd Quarter of 2010) focused on surface environmental issues associated with the hydraulic fracturing process. [2]

This document provides guidance and highlights many of the key considerations to minimize environmental and societal impacts associated with the acquisition, use, management, treatment, and disposal of water and other fluids used in the hydraulic fracturing process, including the following.

1) Operators should engage in proactive communication with local water planning agencies to ensure oil and gas operations do not constrain the resource requirements of local communities and to ensure compliance with all regulatory requirements. Understanding local water needs may help in the development of water storage and management plans that will be acceptable to the communities neighboring oil and gas operations. Also, this proactive communication will help operators in understanding the preferred sources of water to be used for hydraulic fracturing by the local planning agency.

2) Basin-wide hydraulic fracturing planning can be beneficial upon an operator's entry into a new operating area or basin, depending on the scale of the planned operations. The planning effort may include a review of potential water resources and wastewater management opportunities that could be used to support hydraulic fracturing operations. This review should consider the anticipated volumes of water required for basin-wide fracturing in addition to other water requirements for exploration and production operations. Operators should continue to engage local water planning agencies when developing their hydraulic fracturing programs and consider a broad spectrum of competing water requirements and constraints, such as: location and timing of water withdrawal; water source; water transport; fluid handling and storage requirements; flow back water treatment/disposal options; and potential for water recycling.

3) Upon initial development, planning and resource extraction of a new basin, operators should review the available information describing water quality characteristics (surface and groundwater) in the area and, if necessary, proactively work with state and local regulators to assess the baseline characteristics of local groundwater and surface water bodies. Depending on the level of industry involvement in an area, this type of activity may be best handled by a regional industry association, joint industry project, or compact. On a site specific basis, pre-drilling surface and groundwater sampling/analysis should be considered as a means to provide a better understanding of on-site water quality before drilling and hydraulic fracturing operations are initiated.

4) In evaluating potential water sources for hydraulic fracturing programs, an operator's decision will depend upon volume requirements, regulatory and physical availability, competing uses, discussions with local planning agencies, and characteristics of the formation to be fractured (including water quality and compatibility

considerations). A hierarchy of potential sources should be developed based upon local conditions. Where feasible, priority should be assigned to the use of wastewater from other industrial facilities.

5) If water supplies are to be obtained from surface water sources, operators should consider potential issues associated with the timing and location of withdrawals, being cognizant of sensitive watersheds, historical droughts and low flow periods during the year. Operators should also be mindful of periods of the year in which activities such as irrigation and other community and industrial needs place additional demands on local water availability. Additional considerations may include: potential to maintain a stream's designated best use; potential impacts to downstream wetlands and end-users; potential impacts to fish and wildlife; potential aquifer depletion; and any mitigation measures necessary to prevent transfer of invasive species from one surface water body to another.

6) If water supplies are to be obtained from groundwater sources, operators should consider the use of non-potable water where feasible and possible. Using water from such sources may alleviate issues associated with competition for publicly utilized water resources. Alternatively, the use of non-potable water may increase the depth of drilling necessary to reach such resources, and/or the level of treatment necessary to meet specifications for hydraulic fracturing operations.

7) On a regional basis, Operators should typically consider the evaluation of waste management and disposal practices for fluids within their hydraulic fracturing program. This documented evaluation should include information about flow back water characterization and disposition, including consideration of the preferred transport method from the well pad (i.e. truck or piping). Operators should review and evaluate practices regarding waste management and disposal from the process of hydraulic fracturing, including: The preferred disposition (e.g. treatment facility, disposal well, potential reuse, centralized surface impoundment or centralized tank facility) for the basin; treatment capabilities and permit requirements for proposed treatment facilities or disposal wells; and the location, construction and operational information for proposed centralized flow back impoundments.

8) When considering preferred transport options, Operators should assess requirements and constraints associated with fluid transport. Transportation of water to and from a well site may significantly impact both the cost of drilling and operating a well. Alternative strategies should be considered to minimize this expense in addition to potential environmental or social impacts.

9) Operators developing a transportation plan within their hydraulic fracturing program should consider estimated truck volumes within a basin, designation of appropriate off road parking/staging areas, and approved transportation routes. Measures to reduce or mitigate the impacts of transporting large volumes of fracture fluids should be considered. Developing and implementing a detailed fluid transport strategy, as well as working collaboratively with local law enforcement, community leaders and area residents, can aid in enhancing safety and reducing potential impacts.

10) In developing plans for hydraulic fracturing, Operators should strive to minimize the use of additives. When necessary, Operators should assess the feasibility of using more environmentally benign additives. This action could help with addressing concerns associated with fracture fluid management, treatment, and disposal. While desirable, elimination or substitution of an alternative additive is not always feasible as the performance may not provide the same effectiveness as more traditional constituents.

11) Operators should make it a priority to evaluate potential opportunities for beneficial reuse of flow back and produced fluids from hydraulic fracturing, prior to treating for surface discharge or reinjection. Water reuse and/or recycling can be a key enabler to large scale future development. Pursuing this option, however, requires planning and knowledge of chemical additives likely to be used in hydraulic fracturing operations and the general composition of flow back and produced water. Reuse and/or recycling practices require the selection of compatible additives, with focused efforts on the use of environmentally benign constituents that do not impede water treatment initiatives. The wise selection of additives may enhance the quantity of fluids available and provide more options for ultimate use and/or disposal.

Water Management Associated with Hydraulic Fracturing

1 Scope

The purpose of this guidance document is to identify and describe many of the current industry best practices used to minimize environmental and societal impacts associated with the acquisition, use, management, treatment, and disposal of water and other fluids associated with the process of hydraulic fracturing. While this document focuses primarily on issues associated with hydraulic fracturing pursued in deep shale gas development, it also describes the important distinctions related to hydraulic fracturing in other applications.

Moreover, this guidance document focuses on areas associated with the water used for purposes of hydraulic fracturing, and does not address other water management issues and considerations associated with oil and gas exploration, drilling, and production. These topics will be addressed in future API documents. [3]

2 Definitions

2.1
aquifer
A subsurface formation that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

2.2
basin
A closed geologic structure in which the beds dip toward a central location; the youngest rocks are at the center of a basin and are partly or completely ringed by progressively older rocks.

2.3
casing
Steel piping positioned in a wellbore and cemented in place to prevent the soil or rock from caving in. It also serves to isolate fluids, such as water, gas, and oil, from the surrounding geologic formations.

2.4
coal bed methane/coal bed natural gas
CBM/CBNG
A clean-burning natural gas found deep inside and around coal seams. The gas has an affinity to coal and is held in place by pressure from groundwater. CBNG is produced by drilling a wellbore into the coal seam(s), pumping out large volumes of groundwater to reduce the hydrostatic pressure, allowing the gas to dissociate from the coal and flow to the surface.

2.5
completion
The activities and methods to prepare a well for production and following drilling. Includes installation of equipment for production from a gas well.

2.6
disposal well
A well which injects produced water into an underground formation for disposal.

2.7
directional drilling
The technique of drilling at an angle from a surface location to reach a target formation not located directly underneath the well pad.

2.8
flow back
The fracture fluids that return to surface after a hydraulic fracture is completed.

2.9
formation (geologic)
A rock body distinguishable from other rock bodies and useful for mapping or description. Formations may be combined into groups or subdivided into members.

2.10
fracturing fluids
A mixture of water, proppant (often sand), and additives used to hydraulically induce cracks in the target formation.

2.11
gelling agent
Chemical compounds used to enhance the viscosity and increase the amount of proppant a fracturing fluid can carry.

2.12
groundwater
Subsurface water that is in the zone of saturation; source of water for wells, seepage, and springs. The top surface of the groundwater is the "water table."

2.13
horizontal drilling
A drilling procedure in which the wellbore is drilled vertically to a kickoff depth above the target formation and then angled through a wide 90° arc such that the producing portion of the well extends horizontally through the target formation.

2.14
hydraulic fracturing
Injecting fracturing fluids into the target formation at a force exceeding the parting pressure of the rock thus inducing fractures through which oil or natural gas can flow to the wellbore.

2.15
hydrocarbons
Any of numerous organic compounds, such methane (the primarily component of natural gas), that contain only carbon and hydrogen.

2.16
hydrostatic pressure:
The pressure exerted by a fluid at rest due to its inherent physical properties and the amount of pressure being exerted on it from outside forces.

2.17
injection well
A well used to inject fluids into an underground formation either for enhanced recovery or disposal.

2.18
naturally occurring radioactive material
NORM
Low-level, radioactive material that naturally exists in native materials.

2.19
original gas in place
The entire volume of gas contained in the reservoir, regardless of the ability to produce it.

2.20
perforations
The holes created between the casing and liner into the reservoir (subsurface hydrocarbon bearing formation). These holes create the mechanism by which fluid can flow from the reservoir to the inside of the casing, through which oil or gas is produced.

2.21
permeability
A rock's capacity to transmit a fluid; dependent upon the size and shape of pores and interconnecting pore throats. A rock may have significant porosity (many microscopic pores) but have low permeability if the pores are not interconnected. Permeability may also exist or be enhanced through fractures that connect the pores.

2.22
porosity
The voids or openings in a rock, generally defined as the ratio of the volume of all the pores in a geologic formation to the volume of the entire formation.

2.23
primacy
A right that can be granted to state by the federal government that allows state agencies to implement programs with federal oversight. Usually, the states develop their own set of regulations. By statute, states may adopt their own standards, however, these must be at least as protective as the federal standards they replace, and may be even more protective in order to address local conditions. Once these state programs are approved by the relevant federal agency (usually the EPA), the state then has primacy jurisdiction.

2.24
produced water
Any of the many types of water produced from oil and gas wells.

2.25
propping agents/proppant
Silica sand or other particles pumped into a formation during a hydraulic fracturing operation to keep fractures open and maintain permeability.

2.26
reclamation
Rehabilitation of a disturbed area to make it acceptable for designated uses. This normally involves regarding, replacement of topsoil, revegetation, and other work necessary to restore it.

2.27
reservoir
Subsurface hydrocarbon bearing formation.

2.28
shale gas
Natural gas produced from low permeability shale formations.

2.29
slick water
A water based fluid mixed with friction reducing agents, commonly potassium chloride.

2.30
solid waste
Any solid, semi-solid, liquid, or contained gaseous material that is intended for disposal.

2.31
stimulation
Any of several processes used to enhance near wellbore permeability and reservoir permeability, including hydraulic fracturing

2.32
tight gas
Natural gas trapped in a hard rock, sandstone, or limestone formation that is relatively impermeable.

2.33
total dissolved solids
TDS
The dry weight of dissolved material, organic and inorganic, contained in water and usually expressed in parts per million.

2.34
underground injection control program
UIC
A program administered by the Environmental Protection Agency, primacy state, or Indian tribe under the Safe Drinking Water Act to ensure that subsurface emplacement of fluids does not endanger underground sources of drinking water.

2.35
underground source of drinking water
USDW

Defined in 40 *CFR* Section 144.3, as follows: "An aquifer or its portion:

(a) (1) Which supplies any public water system; or

(2) Which contains a 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 mg/l total dissolved solids; and

(b) Which is not an exempted aquifer."

2.36
water quality
The chemical, physical, and biological characteristics of water with respect to its suitability for a particular use.

2.37
watershed
All lands which are enclosed by a continuous hydrologic drainage divide and lay upslope from a specified point on a stream.

2.38
well completion
See **completion**.

3 Introduction and Overview

Hydraulic fracturing is a process involving the injection of fluids into a subsurface geologic formation containing oil and/or gas at a force sufficient to induce fractures through which oil or natural gas can flow to a producing wellbore (see Section 2).

Hydraulic fracturing has played an important role in the development of America's oil and gas resources for nearly 60 years. In the U.S., an estimated 35,000 wells are hydraulically fractured annually and it is estimated that over one million wells have been hydraulically fractured since the first well in the late 1940s. [4] As production from conventional oil and gas fields continues to mature and the shift to nonconventional resources increases, the importance of hydraulic fracturing will continue to escalate as new oil and gas supplies are developed from these precious resources. The escalating importance of these resources is a testament to America's increased reliance on natural gas supplies from unconventional resources such as gas shale, tight gas sands, and coal beds—all resources that generally require hydraulic fracturing to facilitate economically viable natural gas production. [5] In addition, advances in hydraulic fracturing have played a key role in the development of domestic oil reserves, such as those found in the Bakken shale in Montana and North Dakota. [6]

In fact, very few unconventional gas formations in the U.S. and throughout the world would be economically viable without the application of hydraulic fracturing. These very low permeability formations tend to have fine grains with few interconnected pores. Permeability is the measurement of a rock or formation's ability to transmit fluids. In order for natural gas to be produced from low permeability reservoirs, individual gas molecules must find their way through a tortuous path to the well. Single hydraulic fracture stimulation can increase the pathways for gas flow in a formation by several orders of magnitude. [7]

Water requirements for hydraulically fracturing a well may vary widely, but on average required two to four million gallons for deep unconventional shale reservoirs. While these water volumes may seem large, they generally represent a very small percentage of total water use in the areas where fracturing operations occur. [8] Water used for hydraulic fracturing operations can come from a variety of sources, including surface water bodies, municipal water supplies, groundwater, wastewater sources, or be recycled from other sources including previous hydraulic fracturing operations.

Obtaining the water necessary for use in hydraulic fracturing operations can be challenging in some areas, particularly in arid regions. Water volumes required for hydraulic fracturing operations are progressively challenging operators to find new ways to secure reliable, affordable, supplies. In some areas, operators have opted to build large reservoirs to capture water during high runoff events on local rivers when withdrawal is permitted and monitored by water resource authorities, or for future use in storing fracture flow back water. Operators have also explored the option of using treated produced water from existing wells as a potential supply source for hydraulic fracturing operations. The implementation of these practices must conform to local regulatory requirements where operations occur.

The management and disposal of water after it is used for hydraulic fracturing operations may present additional challenges for operators. After a hydraulic fracture stimulation is complete, the fluids returning to the surface within the first seven to fourteen days (often called flow back) will often require treatment for beneficial reuse and/or recycling or be disposed of by injection. This water may contain dissolved constituents from the formation itself along with some of the fracturing fluid constituents initially pumped into the well.

State and local governments, along with the operating and service companies involved in hydraulic fracturing operations, seek to manage produced water in an effective manner that protects surface and groundwater resources while meeting performance specifications. Where possible, operating and service companies seek to reduce future demands on available water resources. Existing state oil and gas regulations are typically designed to protect water resources through the application of specific programmatic elements such as permitting, well construction, well plugging, and temporary abandonment requirements. In addition, state regulatory agencies are customarily charged with overseeing requirements associated with water acquisition, management, treatment, and disposal. [9]

As development of a producing area matures and additional wells are drilled, Operators acquire a better understanding of the hydrocarbon-bearing formation and surrounding geology. With this additional knowledge, drilling and completion techniques are refined and water use requirements for hydraulic fracturing operations become more predictable.

4 The Hydraulic Fracturing Process

4.1 General

Hydraulic fracturing is a well stimulation technique that has been employed in the oil and gas industry since the late 1940s. Hydraulic fracturing is intended to increase the exposed flow area of the productive formation and to connect this area to the well by creating a highly conductive path extending a carefully planned distance outward from the well bore into the targeted hydrocarbon-bearing formation, so that hydrocarbons can flow easily to the well. [10]

4.2 Hydraulic Fracture Stimulation Design

The design of a hydraulic fracture stimulation takes into consideration the type of geologic formation, anticipated well spacing, and the selection of proppant material. Other considerations include the formation temperature and pressure, length of the productive interval to be fractured, reservoir depth, formation rock properties, and the type of fracture fluid available. Long productive intervals may require the hydraulic fracture stimulation to be pumped in several cycles or stages. Each stage of the process is made up of different fluid mixtures that are pumped sequentially with the objective of creating and propagating the hydraulic fracture and placing the proppant. As a matter of course, it takes less than eight hours to pump one stage of a fracture stimulation and some wells may require many stages. Nonetheless, this is a relatively short time period when considering the 30-plus year life expectancy for most gas wells in low permeability formations.

4.3 Hydraulic Fracturing Process

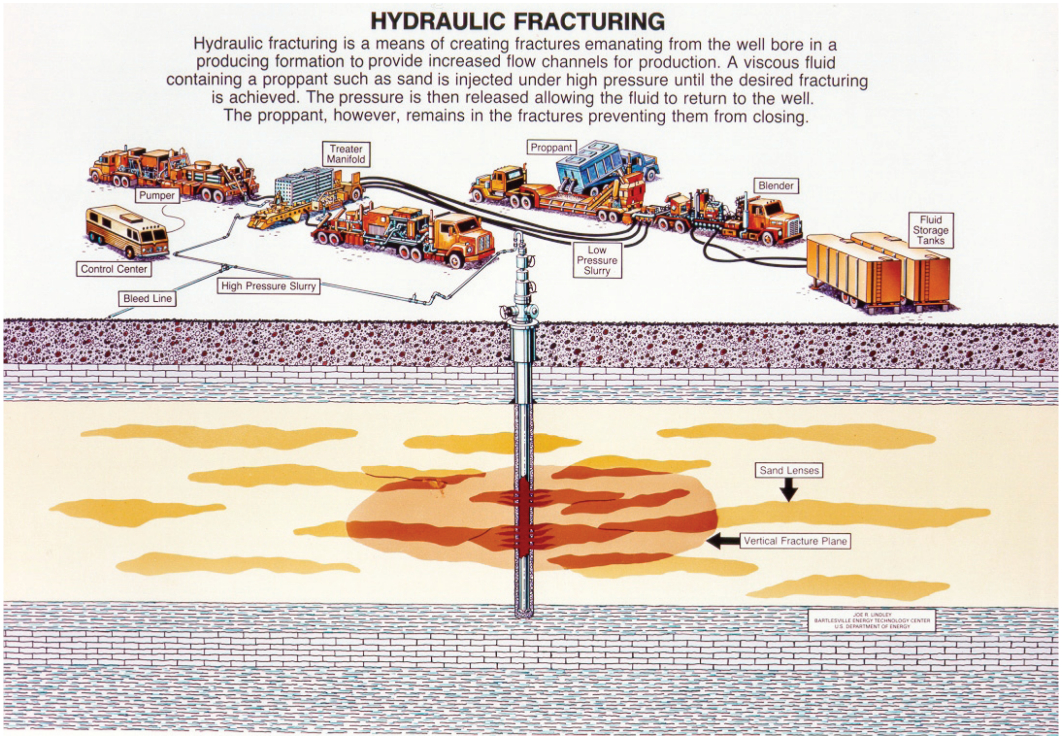
The process of hydraulic fracturing involves pumping a mixture of water, with small amounts of additives at high pressure into the targeted hydrocarbon formation (see Figure 1 and Figure 2). Sometimes gases like nitrogen or carbon dioxide are added to the mixture. Usually the proppant is sand, but other essentially inert materials are used. During the process, narrow cracks (fractures) expand outward from the perforations that serve as flowing channels for natural gas and/or other hydrocarbons trapped in the formation to move to the wellbore. The main “frac” can have small branches connected to it. The placement of proppant keeps the newly created fractures from closing.

Hydraulic fracturing begins with a transport fluid pumped into the production casing through the perforations and into the targeted formation at a sufficient rate and pressure to initiate a fracture; i.e. to crack the rock. This is known as “breaking down” the formation and is followed by a fluid “pad” that widens and extends the defined fracture within the target formation up to several hundred feet from the wellbore. The expansion of the fractures depends on the reservoir and rock properties, boundaries above and below the target zone, the rate at which the fluid is pumped, the total volume of fluid pumped, and the viscosity of the fluid.

In the late 1990s, a technology known as “slickwater fracturing” refined the hydraulic fracturing process to primarily enhance the stimulation of shale formations. Slickwater fractures may also be more economically viable, as fewer additives (which are a factor in the cost of a hydraulic fracture stimulation, [11,12]) are likely required.

4.4 Chemicals Used in Hydraulic Fracturing

Water is the primary component for most hydraulic fracture treatments, representing the vast majority of the total volume of fluid injected during fracturing operations. The proppant is the next largest constituent. Proppant is a granular material, usually sand, which is mixed with the fracture fluids to hold or prop open the fractures that allow gas and water to flow to the well. Proppant materials are selected based on the strength needed to hold the fracture open after the job is completed while maintaining the desired fracture conductivity.



Source: U.S. Department of Energy (http://www.netl.doe.gov/technologies/oil-gas/publications/eordrawings/Color/colhf.pdf)

Figure 1—Schematic Representation of a Hydraulic Fracturing Operation

In addition to water and proppant other additives are essential to successful fracture stimulation. The chemical additives used in the process of hydraulic fracturing typically represent less than 1 % of the volume of the fluid pumped (99 % sand and water) during a "hydraulic fracture treatment" and in many cases can be even less (see Figure 3). [13]

Chemical additives may consist of acids, surfactants, biocides, bactericides, pH stabilizers, gel breakers, in addition to both clay and iron inhibitors along with corrosion and scale inhibitors. Many of these additives are chemicals generally found in common household and food products, clothing, and makeup with an excellent track record of safe use. [14] While a small number of potential fracture fluid additives (such as benzene, ethylene glycol and naphthalene) have been linked to negative health affects at certain exposure levels outside of fracturing operations, these are seldom used and/or used in very small quantities. Most additives contained in fracture fluids present very low risks to human health and the environment. [15] These additives, along with the characteristics of water in the formation being fractured, can often dictate the water management and disposal options that will be technically feasible. [16]

The fracturing fluid is a carefully formulated product. Service providers vary the design of the fluid based on the characteristics of the reservoir formation and specified operator objectives. The composition of the fracturing fluid will vary by basin, contractor, and well. Situation-specific challenges that must be addressed include scale buildup, bacteria growth, proppant transport, iron content, along with fluid stability and breakdown requirements. Addressing each of these criteria may require specific additives to achieve the desired well performance; however, not all wells require each category of additives. Furthermore, while there are many different formulas for each type of additive, usually only one or a few of each category is required at any particular time. A typical fracture fluid will generally include four to six additives, but could require more or less.

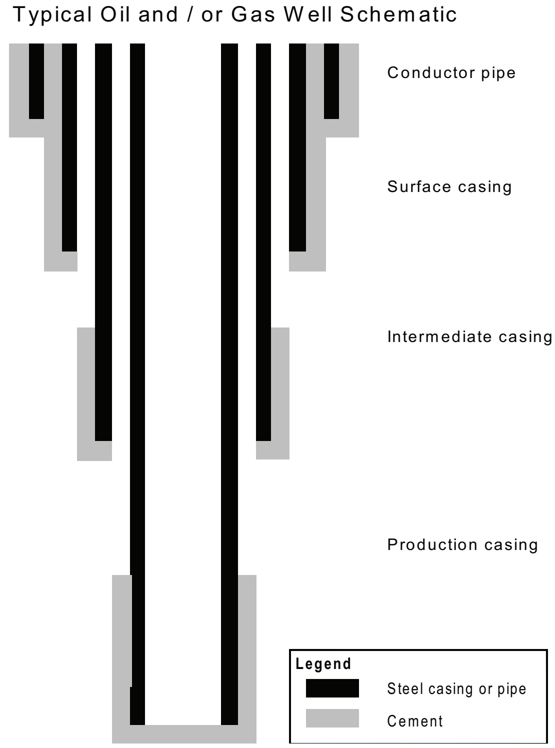
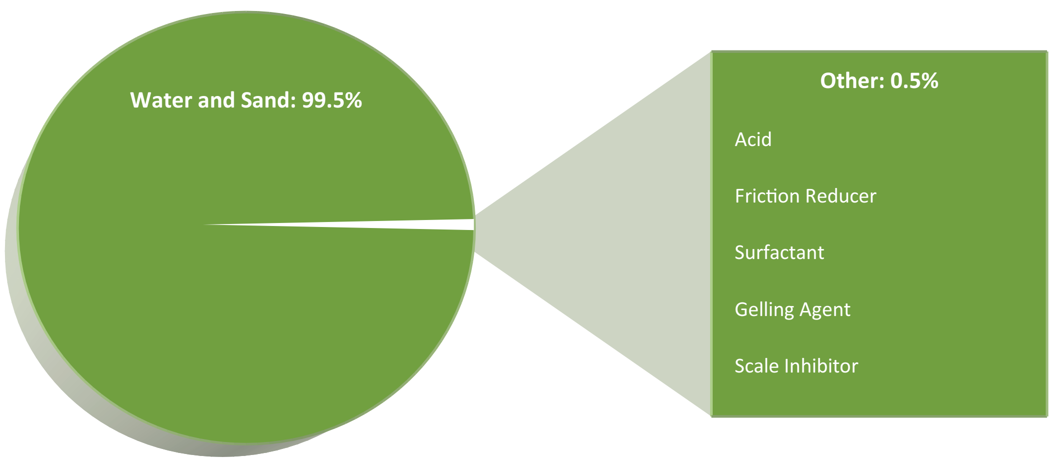


Figure 2—Schematic Representation of Hydraulically Fractured Reservoir From a Horizontal and Vertical Well



Source: Chesapeake Energy Corporation, 2009

Figure 3—Typical Fracture Fluid Composition for Hydraulic Fracturing for a Shale Gas Well

5 Water Use and Management Associated with Hydraulic Fracturing

5.1 General

Hydraulic fracturing operations require the temporary installation and use of surface water storage equipment, chemical storage, mixers, pumps, and other equipment at the well site. Additives are normally delivered in a concentrated (solid or liquid) form, in sealed sacks, tanks, or other containers (see Figure 4). Water is delivered in tanker trucks or via dedicated waterlines. The water may arrive over a period of days or weeks and may be stored on site in tanks or lined pits. Blending of the fracture fluid generally occurs as pumping of the fracture stimulation is underway, so that there is no lengthy on site storage of pre-mixed fracturing fluid. Finally, upon completion of the fracturing operation, recovered fracture fluids in the flow back water must be separated, contained, treated, disposed of, and/or reused.

5.2 Planning Considerations

Considerations associated with water acquisition, use, and management in hydraulic fracturing operations can be categorized in the following different phases.

— Source Water Acquisition—Where will the water supplies needed for hydraulic fracturing operations be acquired?

— Transport—How does the water get from the source to the well site and from the well site to the point of treatment and/or disposal?

Source: Chesapeake Energy Corporation, 2008

Figure 4—Hydraulic Fracturing Well Site for a Marcellus Shale Well

— Storage—What requirements and constraints exist for water storage on site, and how do source water considerations and fracture fluid requirements affect storage requirements?

— Use—How will the water be used, what volume is required, and what must be done (e.g. the addition of proppant and additives) to achieve the fracturing objectives?

— Treatment and Reuse/Recycle—Can the water produced from the fracturing operation be treated and recycled for reuse?

— Treatment and Disposal—If the water is not to be recycled and or reused, what must be done either prior to disposal or with any treatment byproducts?

Regulatory requirements often dictate water management options. These include federal, state and local regulatory authorities. Along with these regulatory authorities, multi-state and regional water permitting agencies may also be responsible for maintaining water quality and supply, such as the Susquehanna River Basin Commission (SRBC) [17] and/or the Delaware River Basin Commission (DRBC), [18] all authorities may dictate water withdrawal and/or disposal options that are available for consideration and use.

Injection wells that may be used for disposal of flow back water and other produced waters are classified as Class IID in EPA's Underground Injection Control (UIC) program [19] and require state or federal permits. The primary objective of the UIC program, whether administered at the state or federal level, is protection of underground sources of drinking water (USDWs) (see 2.35).

In many cases, the responsible authority is a function of the acquisition or disposal option chosen. For example, surface water discharge may be regulated by a different agency than subsurface injection. Therefore, regardless of the regulatory agency with UIC program authority over subsurface injection, new injection wells will require a permit that meets the appropriate state or federal regulatory requirements.

A report prepared for the U.S. Department of Energy provides a comprehensive, practical guide of state oil and gas regulations designed to protect water resources. [20]

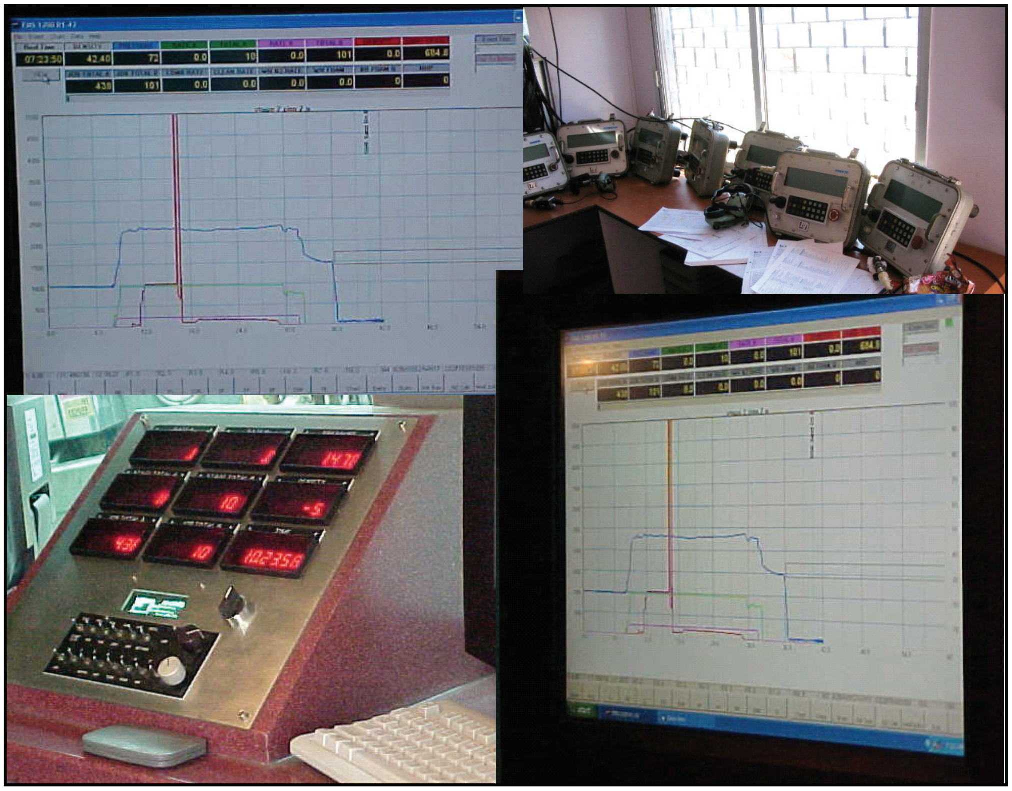
5.3 Water Management Drivers

5.3.1 Fluid Requirements for Successful Fracturing

The primary factor influencing water management and disposal associated with hydraulic fracturing relates to the fluid requirements for a successful fracturing operation. All phases of water management ultimately depend on the requirements the frac fluid properties need for fracturing success. These requirements are the result of the geology, the operating environment, the frac design, the scale of the development process, and the results required for total project success.

The first step in understanding the management of water for hydraulic fracturing involves asking the question: "What does the reservoir rock need, and what will the rock give back after fracturing?" The choice of the fracturing fluid dictates the frac design and what types of fracturing fluids and additives are required. The choice of the frac fluid dictates the fate and transport of fracturing fluids used in fracturing operations, and how the recovered fluids will need to be managed and disposed. [21]

Modern hydraulic fracturing practices are sophisticated, engineered, processes designed to create single fractures or multiple fractures in specific rock strata. These hydraulic fracture treatments are controlled and monitored processes designed for site specific conditions of the reservoir (see Figure 5). These conditions are based on the target product (natural gas or crude oil), the target formation properties and rock fracturing characteristics, the formation water characteristics (e.g. some coalbed methane formations are classified as USDWs), the anticipated water production (formation water vs fracturing flow back water), and the type of well drilled (horizontal or vertical).



Source: Advanced Resources International, Inc. (2009)

Figure 5—Control Room Monitoring a Hydraulic Fracture Stimulation

Understanding the in-situ reservoir conditions is critical to successful stimulations, and in the design of the fracture treatment and fluid used. Hydraulic fracturing designs are continually refined, both during the fracture stimulation itself, as well as over time as more about fracturing the target formation is learned from experience. Thus, while the concepts and general practices are similar, the details of a specific fracture operation can vary substantially from resource to resource, from area to area, from operator to operator, and even from well to well.

The ideal properties of a fracturing fluid relate to its compatibility with the formation rock; its compatibility with the formation fluids; its ability to transfer enough pressure throughout the entire fracture to create a wide fracture, and be able to transport the proppant into the fracture, while breaking back down to a low viscosity fluid for cleanup after the treatment. Finally, and most importantly, the fracture treatment must meet necessary performance specifications.

5.3.2 Factors Influencing Fracturing Fluid Composition

As described in 4.4, there are a wide variety of additives that could be included in the fracturing fluid mix to achieve successful fracturing. These could include proppants, gel and foaming agents, salts, acids, and other fluid additives. Today, operators and service companies are working to maximize the utilization of environmentally benign additives and minimize the amount of additives required.

The characteristics of the resource target determine the required fracture fluid composition. For example, gas shale's may contain various naturally occurring trace metals and compounds that are leached from rocks by acidic water, oxidation, and the action of ions found in brines. Numerous compounds have been formed naturally in the shale, and a stimulation fluid pumped into a well may require various chemicals to counteract any negative effects these compounds may have in the well or the reservoir. Iron compounds found within the Fayetteville shale require an iron sequestering agent so that the compounds of iron will not precipitate out of the fracturing fluid and be deposited within the pore spaces of the reservoir, reducing the reservoir's permeability.

In the Marcellus shale, iron control agents are generally not necessary, but strontium and barium compounds can be present in the flow back water. Strontium and barium scales have very little solubility to the acids that would be used in an attempt to clean up any scale that occurred in the wellbore or the reservoir. Specialized scale inhibitors are thus necessary within the fracturing fluids to eliminate any chance of these scale compounds precipitating out of solution before, during, or after a stimulation job.

Recently developed shale-specific surfactants, combined with friction reducers, have improved the recovery and flow back of stimulation water in shale by improving the inhibition of swelling tendencies of clays that are present in the rock, lowering the resistance to flow in these typically low-pressure reservoirs. The Fayetteville shale is successfully fractured using a cross-linked gel system in very low concentrations with a surfactant, corrosion and scale inhibitors, iron and pH control, biocide, acid and sand. The Huron shale of Kentucky is stimulated using nitrogen and sand or light weight proppant as the major element of the fracturing fluid formulation.

For dry shales or those shale reservoirs that contain clays, making them particularly sensitive to contact with fresh water, foam fracturing—the use of foam as the carrier for the propping agent applied under high pressure—has been the predominant method used for stimulation. Such techniques have been employed for over 30 years and the foam application continues to be the method of choice. Nitrogen or carbon dioxide gas has also been used when fracturing dry shale reservoirs in many basins in the U.S., but success has been limited to relatively shallow shale formations that are very brittle.

5.3.3 Fluid Requirements to Minimize Environmental Concerns

When developing hydraulic fracturing plans, in addition to considerations associated with successfully fracturing the target formations, operators should carefully consider the fluid management and disposal implications of their fracture fluid formulations. The best practice is to use additives that pose minimal risk of possible adverse human health effects to the extent possible in delivering needed fracture effectiveness. While desirable, this type of product substitution is not currently possible in all situations, since effective alternatives are not available for all additives.

6 Obtaining Water Supply For Hydraulic Fracturing

6.1 General

A significant part of a hydraulic fracturing operation involves securing access to reliable sources of water, the timing associated with this accessibility, and the requirements for obtaining permission to secure these supplies. When investigating potential options for securing water supplies to support hydraulic fracturing operations, awareness of competing water needs, water management issues, and the full range of permitting and regulatory requirements in a region is critical. Consultation with appropriate water management agencies is a must, if not required, since they have top level responsibility for the management (including permitting) and protection of water resources.

Proactive communication with local water planning agencies, and the public where appropriate, should be pursued to ensure that oil and gas operations do not disrupt local community water needs. Understanding local water needs can help in the development of water acquisition and management plans that will be acceptable to the communities neighboring oil and gas developments. Although the water needed for drilling and fracturing operations may represent a small volume relative to other requirements, withdrawals associated with large-scale developments, conducted over multiple years, may have a cumulative impact to watersheds and/or groundwater. This potential cumulative impact can be minimized or avoided by working with local water resource managers to develop a plan of when and where withdrawals will occur.

Operators should conduct a detailed, documented review of the identified water sources available in an area that could be used to support hydraulic fracturing operations. Considerations factoring in this review should include:

— evaluating source water requirements,

— fluid handling and storage,

— transportation considerations.

Each of these factors is considered in more detail in 6.2, 6.3 and 6.4.

6.2 Evaluating Source Water Requirements

In evaluating water requirements for hydraulic fracturing, the operator should conduct a comprehensive evaluation of cumulative water demand on a programmatic basis, as well as the timing of these needs at an individual well site. This should include consideration of the water requirements for drilling operations, dust suppression, and emergency response, along with the water requirements for hydraulic fracturing operations. The operator must determine whether or not the sources of water are adequate to support the total operation, with water of the desired quality, and can be accessed when needed for the planned development program.

Specifically, water supply options for hydraulic fracturing will depend on the amount of water that will be required, in aggregate, for the broader, long-term, area-wide development program anticipated. Water sources will need to be appropriate for the forecasted pace and level of development anticipated.

Water for hydraulic fracturing may be obtained from:

1) surface water,

2) groundwater,

3) municipal water suppliers,

4) treated wastewater from municipal and industrial treatment facilities,

5) power plant cooling water, and/or

6) recycled produced water and/or flow back water.

The choice will depend upon volume and water quality requirements, regulatory and physical availability, competing uses, and characteristics of the formation to be fractured (including water quality and compatibility considerations). If possible, wastewater from other industrial facilities should be considered, followed by ground and surface water sources (with the preference over non-potable sources over potable sources), with the least desirable (at least for long-term, large scale development) being municipal water supplies. However, this will depend on local conditions and the availability of ground and surface water resources in proximity to planned operations.

Importantly, not all options may be available for all situations, and the order of preferences can vary from area to area. Moreover, for water sources such as industrial wastewater, power plant cooling water, or recycled flow back water and/or produced water, additional treatment may be required prior to use for fracturing, which may not be possible or feasible and may not deliver the results necessary to assure project success.

Particular issues of concern associated with each of the categories of potential water sources are discussed in more detail in 6.2.1 through 6.2.6.

6.2.1 Surface Water

Many areas draw their principal water supplies from surface water sources, so the large-scale use of this source for hydraulic fracturing operations can possibly impact other competing uses and will be of concern to local water management authorities and other public officials. In some circumstances there will be a need to identify water supply sources capable of meeting the needs for drilling and fracturing water that do not compete or interfere with community needs and other existing uses.

Important considerations in evaluating water supply requirements from surface water sources include the volume of water supplies required, as well as the sequence and scheduling of acquiring these supplies. Withdrawal from surface water bodies, such as rivers, streams, lakes, natural ponds, private stock ponds, etc., may require permits from state or multi-state regulatory agencies, as well as landowner permission. In some regions, water rights are also a key consideration. [22] In addition, water quality standards and regulations established by these regulatory authorities may prohibit any alteration in flow that would impair a fresh surface water body's highest priority use, which is often defined by local water management authorities. Also consideration should be given to ensure Moreover, water withdrawals during periods of low stream flow do not affect fish and other aquatic life, fishing and other recreational activities, municipal water supplies, and other industrial facilities, such as power plants.

Water withdrawal permits can require compliance with specific metering, monitoring, reporting, record keeping, and other consumptive use requirements, which could include specifications for the minimum quantity of water that must pass a specific point downstream of the water intake in order for a withdrawal to occur. In the case where stream flow is less than the prescribed minimum quantity, withdrawals may be required to be reduced or cease.

The operator should consider the issues associated with the timing and location of withdrawals since impacted watersheds may be sensitive, especially in drought years, during low flow periods during the years, or during periods of the year when activities such as irrigation place additional demands on the surface supply of water. In making requests for surface water withdrawal, operators should consider the following potential impacts that could control the timing and volume available:

— ownership, allocation, or appropriation of existing water resources;

— water volume available for other needs, including public water supply;

— degradation of a stream's designated best use;

— impacts to downstream habitats and users;

— impacts to fish and wildlife;

— aquifer volume diminishment;

— mitigation measures to prevent transfer of invasive species from one surface water body to another (as a result of water withdrawal and subsequent discharge into another surface water body).

State, regional, or local water management authorities may request that the operator identify the source of water to be used for supplying hydraulic fracturing operations, and provide information about any newly proposed surface water source that has not been previously approved for use. Information that must be supplied could include the withdrawal location and the size of the upstream drainage area and available stream gauge data, along with demonstration of compliance relative to stream flow standards. For obtaining approval and/or maintaining a good relationship with regulatory bodies, local communities, and other stake-holders it is obvious that requests for water withdrawals from sensitive watersheds should be carefully considered for their wider impact.

Finally, in some jurisdictions, a variety of permits may be required for the transport of water via pipes, canals or streams; as well as by tanker truck. Moreover, equipment or structures used for surface water withdrawal, such as standpipes, may also require permits.

One alternative that could be considered and that may be acceptable to local water management authorities is water withdrawal programs that make use of seasonal changes in river flow, in order to capture water when surface water flows are greatest. This would likely involve the use of large-scale water diversion and storage impoundments (see Figure 6).

As described in more detail below, additional regulatory requirements are likely to be associated with such facilities. Diverting water to storage impoundments during periods of high flow allows withdrawals at a time of peak water availability which avoids impacts to municipal drinking water supplies or to aquatic or riparian communities. However, operators need to keep in mind that this approach will normally require the development of sufficient water storage capabilities to meet the overall requirements of drilling and hydraulic fracturing plans over the course of a season, year, or perhaps even over a multi-year period (to plan for possible periods of drought).

Another alternative to ensuring water supply is to use abandoned surface coal mining pits for the storage of water. Having more permanent facilities such as this may provide for the installation of a comprehensive water distribution system that can be matched to development plans. Of course, the water quality in such impoundments must meet with operational requirements and will likely vary depending on the nature of the exposed overburden present in such areas. Moreover, these pits must meet all regulatory requirements for such surface impoundments.

Another simple method that can be used is to excavate low lying areas and allow for rain water harvesting. The potential use of such a method requires planning as it may take a long time for the excavation to fill up, depending on precipitation conditions. This option should be discussed with state, regional, or local water management authorities to ensure compliance with stormwater runoff program elements.

Source: Little Red River Reservoir—Chesapeake Energy Corporation, 2008

Figure 6—Example of Diversion Pond Construction

6.2.2 Groundwater

Most regulatory programs with jurisdiction over oil and gas operations, have a strong focus on groundwater. Withdrawals from groundwater, especially USDWs, will almost always require permits from state or multi-state regulatory agencies.

Whenever practicable, operators should consider using non-potable water for drilling and hydraulic fracturing. Many of the concerns about water supply can be avoided if lower-quality groundwater sources, such as water with > 10,000 ppm total dissolved solids (TDS) are used. For example, in some cases, operators are using saline waters with up to 30,000 ppm, content as a water source for hydraulic fracturing where fresh water availability may be uncertain or limited. [23] However, this may require the drilling of source water wells that are deeper than publicly used potable water aquifers. Deeper water may contain additional constituents that could require treating, but it can alleviate issues of competition with publicly utilized water resources.

For example, domestic and municipal water wells in the Fort Worth Basin access the Upper Trinity aquifer to supply fresh water to the public. Operators working in the Barnett shale are drilling to the Lower Trinity aquifer to supply water for drilling and hydraulic fracturing. The Lower Trinity water has a higher TDS content that would not be suitable for domestic use without extensive water treatment. Again, in order to ensure that drilling deep into useable aquifers will not negatively impact the available freshwater zones, operators should consult with state, regional, or local water management authorities and consider undertaking a study to determine the feasibility of success in such areas.

Operators may need to address many of the same types of considerations for groundwater as for surface water. The primary concern regarding groundwater withdrawal is temporary aquifer volume diminishment. In some areas, the availability of fresh groundwater is limited, so withdrawal limitations could be imposed. Operators may be directed to other shallow alluvial aquifers from which they can withdraw groundwater. Louisiana, for example, has such requirements. [24]

Another groundwater protection consideration is locating water source wells for oil and gas operations at an appropriate distance from municipal, public, or private water supply wells. Again in consideration of hydrologic conditions, public or private water supply wells and fresh water springs within a defined distance of any proposed drilling location for a water supply well, including locations of other water supply wells, should be identified and their characteristics evaluated, both in terms of production capacity and water quality. Depending on the available data, this may include testing of the water currently available from these sources. This will require locating the public and private water wells and obtaining information about their depth, completed interval and use (including whether the well is public or private, community or non-community, and the type of facility or establishment if it is not a private residence). This information is normally available from state and local regulatory authorities, however direct contact with property owners and/or tenants may be appropriate if undocumented water wells are suspected. [25]

Guidance for groundwater protection related to well drilling and hydraulic fracturing operations are the subject of a separate API guidance document, [26] the purpose of which is to provide industry guidance for well construction and integrity for wells that will be hydraulically fractured. The objective is to ensure that USDWs and the environment will be protected, while delivering successful and effective fractures and overall successful projects. Specifically, maintaining well integrity is featured as the key design principle of all oil and gas production wells, which is essential for two primary reasons:

— to isolate the internal conduit of the well from the surface and subsurface environment,

— to isolate and contain the well's produced fluid to a production conduit within the well.

6.2.3 Municipal Water Supplies

Obtaining water supplies from municipal water suppliers can be considered, but again, the water needs for fracturing would need to be balanced with other uses and community needs. This option might be limited, since some areas may be suffering from current water supply constraints, especially during periods of drought, so the long term reliability of supplies from municipal water suppliers needs to be carefully evaluated.

6.2.4 Wastewater and Power Plant Cooling Water

Other possible options for source water to support hydraulic fracturing operations that could be considered are municipal wastewater, industrial wastewater, and/or power plant cooling water. Clearly, the specifications of this water source need to be compatible with the target formation and the plan for fracturing as well as whether treating is technically possible and whether treatment can deliver an overall successful project. In some cases, required water specification could be achieved with the proper mixing of supplies from these sources with supplies from surface water or groundwater sources.

6.2.5 Reservoir Water and Recycled Flow Back Water

Produced reservoir water and recycled flow back water can be treated and reused for fracturing, depending on the quality of the water. Natural formation water has been in contact with the reservoir formation for millions of years and thus contains minerals native to the reservoir rock. Some of this formation water is recovered with the flow back water after hydraulic fracturing, so that both contribute to the characteristics of the flow back water. The salinity, TDS, and overall quality of this formation/flow back water mixture can vary by geologic basin and specific rock strata. For example, water salinity can range from brackish (5,000 parts per million (ppm) to 35,000 ppm TDS), to saline (35,000 ppm to 50,000 ppm TDS), to supersaturated brine (50,000 ppm to >200,000 ppm TDS). Other water quality characteristics that may influence water management options for fracturing operations include concentrations of hydrocarbons (analyzed as oil and grease), suspended solids, soluble organics, iron, calcium, magnesium, and trace constituents such as benzene, boron, silicates, and possibly other constituents.

Several efforts are underway to examine the conditions where the use of reservoir water and recycled flow back water for fracturing operations may be economically viable. [27] Typically, the water must be treated. This option is discussed in more detail elsewhere in this guidance document.

Some coalbed methane operations may also have discharge water that is appropriate for hydraulic fracturing use.

Finally, operators should be aware that black shales, as well as other formations that are often the target formations for hydraulic fracturing operations, sometimes contain trace levels of naturally occurring radioactive materials (NORM). Gamma ray logs indicate, for example, that this is true of the Marcellus shale. Gas wells can bring NORM to the surface in the cuttings, flow back fluid and production brine, and NORM can accumulate in pipes and tanks (pipe scale). NORM contained in the discharge of fracturing fluids or production brine may be subject to discharge limitations. The Environmental Sciences Division of Argonne National Laboratory has addressed exploration and production (E&P) NORM disposal options in detail and maintains a Drilling Waste Management Information System website [28] that links to regulatory agencies in all oil and gas producing states. API also has published several documents providing guidance on the management of NORM in oil and gas operations. [29]

6.2.6 Make-up Water Requirements, Availability and Quality

In situations where water is recycled and/or reused, or additional sources of industrial wastewater make some contribution to supply water for fracturing operations, additional make up water may be required. In these cases, water management alternatives to be considered will depend on the volume and quality of both the recycled water and the make up water, to ensure compatibility with each other and with the formation being fractured.

6.3 Fluid Handling And Storage Considerations

6.3.1 General

Fluids handled at the well site both before and after hydraulic fracturing often must be stored on site, and must be transported from the source of supply to the point of ultimate treatment and/or disposal. Fluids used for hydraulic fracturing will generally be stored onsite in tanks or lined surface impoundments. Returned fluids, or flow back, may also be directed to tanks or lined pits.

The volume of initial flow back water recovered during the first 30 days following the completion of hydraulic fracturing operations may account for less than 10 % to more than 70 % of the original fracture fluid volume. The vast majority of fracturing fluid injected is recovered in a very short period of time, of several hours up to a maximum of several months.

All components of fracture fluids, including water, additives and proppants, should be managed properly on site before, during, and after the fracturing process. Ideally, fracture fluid components should all be blended into the fluids used for fracturing only when needed. Any unused products should be removed from the location by the contractor or operator as appropriate. The job planning process should consider unexpected delays of the fracture operations and ensure that materials are properly managed.

While flow back fluids are a federally E&P exempt waste [i.e. exempt from hazardous waste requirements under the Resource Conservation and Recovery Act (RCRA)], they still need to be addressed under any applicable state regulations. In the unlikely event that small amounts of products used to fracture a well are accidentally leaked they may become RCRA managed waste. Any leak to the ground creates a waste that should be managed and disposed of properly in accordance with all rules, regulations, and permits.

The Material Safety Data Sheet (MSDS) for each additive should be obtained from the supplier or manufacturer, be reviewed prior to using the additive, and be readily available at the job site. The MSDS will contain information about proper storage, hazards to the environment, spill clean-up procedures and other information to minimize environmental impacts. Addressing these issues is the subject of other API documents. [30]

Operators may be required to provide information about their water management and storage operations at the site. Such information may include the following:

— information about the design and capacity of storage impoundments and/or tanks;

— information about the number, individual and total capacity of receiving tanks on the well pad for flow back water;

— description of planned public access restrictions, including physical barriers and distance to edge of well pad;

— how liners are to be placed to prevent possible leakage from such impoundments.

6.3.2 Storage in Surface Impoundments

If lined impoundments or pits are used for storage of fracture fluids or flow back water, the pits must comply with applicable rules, regulations, good industry practice, and liner specifications. However, it is important to recognize that storage impoundments containing fluids associated with fracturing operations will likely contain significantly larger volumes of fluids than from conventional operations. To enhance efficiency and limit the number of impounds, some operators are considering the use of centralized impoundments to manage flow backwater. Thus, these impoundments will be designed and constructed in such a manner as to provide structural integrity for the life of their operation. Proper design and installation is imperative to the objective of preventing a failure or unintended discharge.

All surface impoundments, including those used for storing fracture fluids, will be constructed in accordance with existing state and federal regulations. In some states, use of such an impoundment requires a prior authorization from the regulatory agency; and in some, a separate permit is required specifically for the pit's explicit functional use. [31]

Depending upon the fluids being placed in the impoundment, the duration of the storage and the soil conditions, an impound lining may be necessary to prevent infiltration of fluids into the subsurface. In most states, pits must have a natural or artificial liner designed to prevent the downward movement of pit fluids into the subsurface. Pits used for long term storage of fluids should be placed an appropriate distance from surface water to prevent unlikely overflows from reaching the surface water.

In addition, to ensure the safe operation and maintenance of any impoundment, an inspection and maintenance plan should be followed.

Additional information may be required by regulatory authorities for centralized surface impoundments for fracture fluids. For such facilities, requirements may include an initial review of site topography, geology and hydrogeology, especially if such impoundments are within defined distances of a water reservoir; perennial or intermittent stream, wetland, storm drain, lake or pond, or a public or private water well or domestic supply spring.

6.3.3 Storage in Tanks

Many operators store fluids used in and produced from fracturing operations in steel tanks, in addition to or rather than earthen pits. These tanks must meet appropriate state and federal standards, which may be specific to the use of the tank (e.g. use for temporary tank flow back water or more permanent production tank batteries).

6.4 Transportation Considerations

Before fracturing, water, sand and any other additives are generally delivered separately to the well site, in accordance with Department of Transportation and state regulations. Water is generally delivered in tanker trucks that may arrive over a period of days or weeks, or via pipelines from a supply source or treatment/recycling facility.

Water supply and management approaches should take into consideration the requirements and constraints associated with fluid transport. Transportation of water to and from a well site can be a major expense and major activity. To manage the expense, improve efficiency, and limit other impacts, several strategies are used by operators.

Trucking costs can be the biggest part of the water management expense. One option to consider as an alternative to trucking is the use of temporary or permanent surface pipelines. Producers are increasingly turning to temporary surface pipelines to transport fresh water to impoundments and to well sites. However, in many situations, the transport of fluids associated with hydraulic fracturing by surface pipeline may not be practical, cost effective, or even feasible. [32]

The use of multi-well pads make the use of central water storage easier, reduces truck traffic, and allows for easier and centralized management of flow back water. In some cases it can enhance the option of pipeline transport of water.

In order to make truck transportation more efficient, cost effective and less impactful operators may want to consider constructing storage ponds and drilling source wells in cooperation with private property owners. The opportunity to help a private landowner by constructing or improving an existing pond, drilling a water well, and/or improving the roads on their property can be a win-win situation for the operator and the landowner. It provides close access for the operator to a water source, and adds improvements to the property that benefit the landowner.

Operators should also consider utilizing agricultural techniques to transport the water used near the water sources. Large diameter, aluminum agricultural pipe is sometimes used to move the fresh water from the source to locations within a few miles where drilling and hydraulic fracturing activities are occurring. Water use by the shale gas industry has spurred agricultural and field service companies to supply the temporary pipe, pumps, installation, and removal as a business pursuit in some areas.

When fracture fluids are transported by truck, operators should develop a basin-wide trucking plan that includes the estimated amount of trucking required, hours of operations, appropriate off road parking/staging areas, and routes. Considerations for the trucking plan for large volumes of fracture fluid include the following:

— seek public input on route selection to maximize efficient driving and public safety;

— avoidance of peak traffic hours, school bus hours, community events, and overnight quiet periods;

— coordination with local emergency management agencies and highway departments;

— upgrades and improvements to roads that will be traveled frequently to and from many different well sites;

— advance public notice of any necessary detours or road/lane closures;

— adequate off-road parking and delivery areas at the site.

7 Water Management And Disposal Associated With Hydraulic Fracturing

7.1 General

In general, well permits will specify that all fluids, including fracture fluids and flow back water, must be removed from the well site. In addition, any temporary storage pits used for fracturing fluids must be removed as part of reclamation.

Water used in the hydraulic fracturing process is usually managed and disposed of in one of three ways:

1) injected in permitted disposal wells under a UIC regulatory program;

2) delivered to water treatment facilities depending on permitting (in certain regions of the country, the water is actually treated to remove pollutants and achieve all regulated specifications and then surface discharged);

3) reused/recycled.

Disposal options are dependent on a variety of factors, including the availability of suitable injection zones and the possibility of obtaining permits for injection into these zones; the capacity of commercial and/or municipal water treatment facilities; and the ability of either operators or such plants to successfully obtain surface water discharge permits.

While treatment of produced fluids from some fracturing operations remains an option in some jurisdictions, requirements associated with the use of this option are likely to continue to become more stringent. [33] Operators should prepare for proper management and disposal of fluids associated with hydraulic fracturing operations. Considerations for fluid management should include ñ flow back water disposition, including the planned transport off of the well pad (truck or piping), and information about any proposed piping; planned disposition (e.g. treatment facility, disposal well, reuse, centralized surface impoundment or centralized tank facility); identification and permit numbers for any proposed treatment facility or disposal well, and the location and construction and operational information for any proposed centralized flow back water surface impoundment.

Operators should work proactively with state, regional and local regulators to ensure surface and groundwater quality is adequately described. This may include supporting regional sampling/analytical programs to provide general information. This information will provide a better understanding of regional and local water quality before extensive drilling and hydraulic fracturing are initiated, and will help inform the local community about existing groundwater quality. Operators should consider collecting additional site specific baseline water samples collected from public and private wells near planned operations, as well as from nearby surface water bodies prior to drilling specific wells if existing information is not adequate. The actual parameters to be tested will depend somewhat on site specific geology and hydrology. Testing parameters should include, but are not limited to TDS, total suspended solids (TSS), chlorides, carbonates, bicarbonates, sulfate, barium, strontium, arsenic, surfactants, methane, hydrogen sulfide, NORM, and benzene.

Primary potential destinations for flow back/production fluids generally include the following:

— injection wells, which are regulated under either a state or federal UIC program;

— municipal waste water treatment facilities;

— industrial waste treatment facilities;

— other industrial uses;

— fracture flow back water recycling/reuse.

Each of these is discussed in more detail in 7.2 through 7.6.

7.2 Injection Wells

Disposal of flow back fluids through injection, where an injection zone is available, is widely recognized as being environmentally sound, is well regulated, and has been proven effective. API has published several documents related to injection wells and subsurface disposal. [34] In order to handle the expected amount of water associated with large scale developments, additional injection wells in an area may need to be drilled and permitted.

Injection wells for disposal of brine associated with oil and gas operations are classified as Class IID in EPA's UIC program [35] and require state or federal permits. The primary objective of the UIC program, whether administered at the state or federal level, is protection of USDWs. Therefore, whether the EPA or the state regulatory agency has UIC program authority over subsurface injection, new injection wells will require an injection well permit that meets the appropriate state and/or federal regulatory requirements.

7.3 Municipal Waste Water Treatment Facilities

Municipal wastewater treatment plants or commercial treatment facilities could be available as a treatment and disposal option for fracture fluid flow back and/or other produced waters. However, the availability of municipal or commercial treatment plants may be limited to larger urban areas where treatment facilities with sufficient available capacity already exist. Moreover, as with underground injection, transportation to treatment facilities may or may not be practical.

Municipal sewage treatment facilities, often know as Publicly Owned Treatment Works (POTWs) must have a state-approved pretreatment program for accepting any industrial waste. POTWs generally must also notify appropriate regulatory authorities of any new industrial waste they plan to receive at their facility and certify that their facility is capable of treating the pollutants that are expected to be in that industrial waste. POTWs are generally required to perform certain analyses to ensure they can handle the waste without upsetting their system or causing a problem in the receiving water. Ultimately, approval is required of such analysis and modifications to the POTW's permits to ensure water quality standards in receiving waters are maintained at all times. Thus, the POTW may require that operators provide information pertaining to the chemical composition of the hydraulic fracturing additives in an effort to assist in this review.

7.4 Industrial Waste Treatment Facilities

Many operators believe that future disposal needs will unlikely be met by POTW's due to regulatory and other restrictions in the future. Thus, an alternative solution may be the construction of private or industry-owned treating facilities, perhaps built and operated by an industry cooperative or an environmental services company. In several regions, the evolving practice is to set up temporary treatment facilities located in active drilling development areas or to treat the waste stream onsite with mobile facilities. The temporary facilities can alleviate/reduce the trucking of waste streams by the use of transitory pipeline systems that serve local wells.

These facilities may need to be permitted by the appropriate local, state, and/or federal regulatory authorities. Permits for a dedicated treatment facility would include specific discharge limitations and monitoring requirements.

7.5 Other Industrial Uses

Other industrial uses for flow back water could also be considered, but will be highly dependent on site specific considerations, and some treatment would likely be required. One such example could be the use of the flow back water to support drilling operations. Another is the use of this water as source water for water flooding operations, where water is injected into a partially depleted oil reservoir to displace additional oil and increase recovery. Waterflood operations are regulated under state regulations and/or EPA's UIC Program. These authorities would review the proposed use of flow back fluids from hydraulic fracturing operations as a waterflood injectate. Often, water injection operations that are authorized by rule are required to submit an analysis of the injectate any time it changes; such operations are usually required to modify their permits to inject water from a new source.

7.6 Fracture Flow Back Water Recycling/Reuse

In some cases, it might be more practical to treat the water to a quality that could be reused for a subsequent hydraulic fracturing job, or other use, rather than treating to meet requirements for surface discharge. Consequently, operators should consider options for the recycling of fracture treatment flow back fluid. Water reuse/recycling can be a key enabler to large scale future developments that use fracturing. This is already being considered in some areas. This ability to reuse fracturing fluid will depend on the degree of treatment required and the volume of make up water necessary for reuse.

Options considered will depend on the rates and total water volumes to be treated, water constituents that need to be treated, their concentrations, their treatability, and water reuse or discharge requirements. The reuse of flow back water can provide a practical solution that overcomes many of the constraints imposed by limited source water supplies and difficult disposal situations.

For example, technological advancements from other water treating industries are being adapted to work with the high saline water that results from hydraulic fracturing and include reverse osmosis and membrane innovations. Distillation technology is in the process of refinement to improve the 75 % to 80 % treating effectiveness of the current return water. [36] However, distillation is also a very energy intensive process. It may only become an option for all operations with technological improvements to increase the treatment effectiveness and the overall efficiency of the process.

Pursuing this option requires careful planning and knowledge of the composition of the flow back water and/or the produced reservoir water. It requires proper chemical selection and design and additives that do not create major water treatment issues. Technology advances are making it more economical to treat these fluids with better results in water quality. The treatment of these fluids may greatly enhance the quantity of acceptable, reusable fluids and provide more options for ultimate disposal.

Such treatment facilities either could be run by operators, or could function as stand alone, independent commercial enterprises, as described previously.

A number of treatment approaches exist, and many others are being developed and modified to address the specific treatment needs of flow back water in different operating regions. [37,38,39,40] Processes that can be utilized for water treatment include but are not limited to filtration, aeration and sedimentation, biological treatment, demineralization, thermal distillation, condensation, reverse osmosis, [41] ionization, natural evaporation, freeze/thaw, crystallization, and ozonation.

This is by no means an exhaustive list, and new alternatives are continuously being considered and evaluated. Operators are encouraged to keep abreast of new developments in this field.

Given the complexity of hydraulic fracturing and flow back fluids, it is likely that multiple processes will be required in many, if not most cases. Obviously, key considerations are the performance and cost-effectiveness of the water treatment process along with the volume and environmental considerations associated with the resulting concentrate.

Additional information on the comparative performance of potential water treatment technologies could be obtained from the following websites:

— http://www.pe.tamu.edu/crisman/,

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