Chapter 1

Introduction

1. Introduction

1.1. Background

Since the early 2000s, oil and natural gas production in the United States has been transformed through the technological innovations of hydraulic fracturing and directional drilling. Hydraulic fracturing is a stimulation technique used to increase production of oil and gas. It involves the injection of fluids under pressures great enough to fracture the oil- and gas-production formations. Hydraulic fracturing in combination with advanced directional drilling techniques has made it possible to economically extract hydrocarbons from unconventional resources, such as shale, tight formations, and coalbeds.[1] It can also enhance production from conventional resources. The surge in use of hydraulic fracturing and associated technologies has significantly increased domestic energy supplies (see Chapter 2) and brought economic benefits to many areas of the United States.

The growth in domestic oil and gas exploration and production– the direct result of the expanded use of hydraulic fracturing– has also raised concerns about its potential for impacts to human health and the environment. Specific concerns have been raised by the public about the effects of hydraulic fracturing on the quality and quantity of drinking water resources. Some residents living close to oil and gas production well sites report changes in the quality of ground water resources used for drinking water and assert that hydraulic fracturing is responsible for these changes. Other concerns include competition for water between hydraulic fracturing operations and other water users, especially in areas of the country experiencing drought, and the disposal of wastewater generated from hydraulic fracturing. In response to public concerns, the U.S. Congress urged the U.S. Environmental Protection Agency (EPA) to study the relationship between hydraulic fracturing and drinking water (H.R. Rep. 111-316, 2009). In 2011, the EPA published its *Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources* (U.S. EPA, 2011c; hereafter Study Plan). The research described in the Study Plan began the same year. In 2012, the EPA issued *Potential Impacts of Hydraulic Fracturing on Drinking Water Resources: Progress Report* (U.S. EPA, 2012f; hereafter Progress Report) in order to update the public on the status of the research being conducted under the Study Plan. In this report, we review and synthesize scientific literature, including the publications resulting from the EPA's research and information provided by stakeholders, to assess the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources. This report also identifies factors affecting the frequency or severity of any potential impacts.

1.2. Scope

This assessment focuses on hydraulic fracturing in onshore oil and gas wells in the contiguous United States; limited available information on hydraulic fracturing in Alaska is included. To the

[1] Unconventional resources is an umbrella term for oil and natural gas that is produced by means that do not meet the criteria for conventional production. What has qualified as unconventional at any particular time is a complex function of resource characteristics, the available exploration and production technologies, the economic environment, and the scale, frequency, and duration of production from the resource (see Text Box 2-2).

extent possible, this assessment addresses hydraulic fracturing in all types of oil- and gas-bearing formations in which it is conducted, including shale, so-called 'tight' formations (e.g., certain sandstones, siltstones, and carbonates), coalbeds, and conventional reservoirs. It tends to focus on hydraulic fracturing in shale, which reflects the relatively large amount of literature and available data on hydraulic fracturing in this type of geologic formation.

The scope of activities examined in this assessment is defined by the hydraulic fracturing water cycle. This cycle encompasses activities involving water that support hydraulic fracturing and consists of five stages: (1) acquisition of water needed to create hydraulic fracturing fluids; (2) mixing of water and chemicals on the well pad to create hydraulic fracturing fluids; (3) injection of hydraulic fracturing fluids into the well to fracture the geologic formation; (4) management of flowback and produced water on the well pad and in transit for reuse, treatment, or disposal; and (5) reuse, treatment and discharge, or disposal of hydraulic fracturing wastewater (see Figure 1-1).[1,2,3,4]

Activities within the hydraulic fracturing water cycle can take place on or near the well pad or some distance away. On-site activities include mixing and injecting hydraulic fracturing fluids and capturing flowback and produced water. Water withdrawals and wastewater treatment and disposal may occur in the same watershed, adjacent watersheds, or watersheds many miles away from the production site.

This assessment focuses on impacts on drinking water resource quantity and quality. Consistent with the Study Plan (U.S. EPA, 2011c), drinking water resources are defined broadly within this report as any body of ground water or surface water that now serves, or in the future could serve, as a source of drinking water for public or private use. This is broader than most regulatory definitions of "drinking water" and encompasses both fresh and non-fresh bodies of water, since trends indicate both types of water bodies are now and in the future will be used as sources of drinking water (see Chapter 3). We note that drinking water resources provide not only water that individuals actually drink but also water used for many additional purposes such as cooking and bathing.

We assess potential effects on drinking water resources from business-as-usual operations as well as from accidents and unintended releases that may occur during the hydraulic fracturing water cycle (see Table 1-1).

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[1] Hydraulic fracturing fluids are engineered fluids, typically consisting of a base fluid, additives, and proppants, that are pumped under high pressure into the well to create and hold open fractures in the formation.
[2] Flowback is defined multiple ways in the literature. In general, it is either fluids predominantly containing hydraulic fracturing fluid that return from a well to the surface or a process used to prepare the well for production (see Chapter 7).
[3] Produced water is water that flows from oil and gas wells.
[4] Hydraulic fracturing wastewater is flowback and produced water that is managed using practices that include but are not limited to reuse in subsequent hydraulic fracturing operations, treatment and discharge, and injection into disposal wells (see Chapter 8).

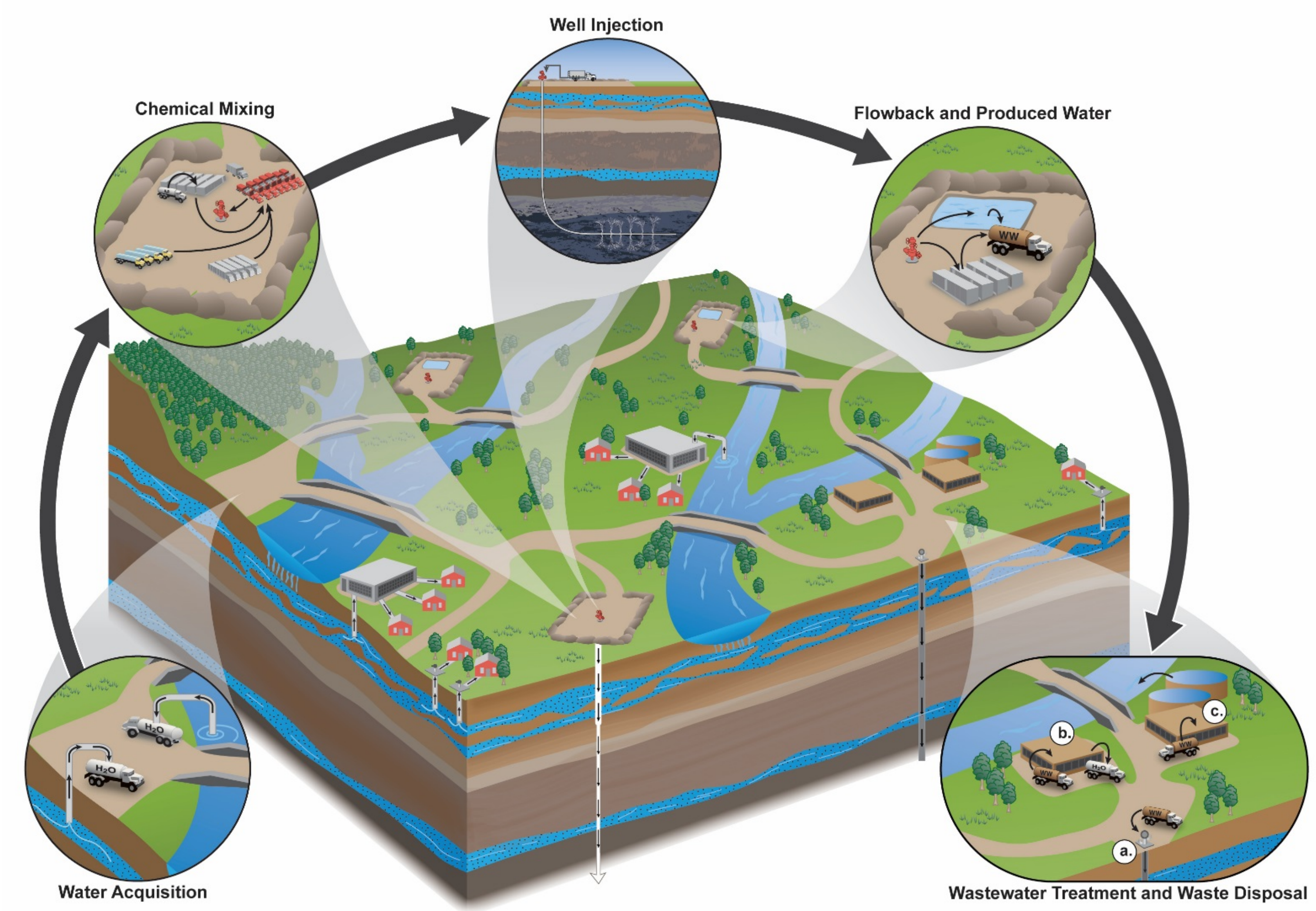

Figure 1-1. Conceptualized view of the stages of the hydraulic fracturing water cycle.

Shown here is a generalized landscape depicting the activities of the hydraulic fracturing water cycle and their relationship to each other, as well as their relationship to drinking water resources. Activities may take place in the same watershed or different watersheds and close to or far from drinking water resources. Drinking water resources are any body of ground water or surface water that now serves, or in the future could serve, as a source of drinking water for public or private use. Arrows depict the movement of water and chemicals. Specific activities in the "Wastewater Treatment and Waste Disposal" inset are (a) underground injection control (UIC) well disposal, (b) wastewater treatment and reuse, and (c) wastewater treatment and discharge at a centralized waste treatment (CWT) facility. Note: Figure not to scale.

Table 1-1. Stages of the hydraulic fracturing water cycle have various potential effects on drinking water resources.

The potential effects addressed in this assessment, and how they are related to the activities within each stage, are summarized here.

Water cycle stage	Activities or processes potentially affecting drinking water resources	Potential drinking water effects addressed in this assessment			
		Quality		Quantity	
		Ground water	Surface water	Ground water	Surface water
Water acquisition	Water withdrawals	X	X	X	X
Chemical mixing	Spills of hydraulic fracturing fluids	X	X		
Well injection	Subsurface migration of hydraulic fracturing fluids or formation fluids	X	X		
Flowback and produced water	Spills of flowback or produced water	X	X		
Wastewater treatment and waste disposal	Discharge of untreated or inadequately treated wastewater and inappropriate disposal of waste solids	X	X		

As part of the assessment, we evaluated immediate, near-term, and long-term effects on drinking water resources. For example, we considered how surface spills of hydraulic fracturing fluids may potentially have immediate or near-term impacts on neighboring surface water and shallow ground water quality (see Chapters 5 and 7). We also considered how the potential release of hydraulic fracturing fluids in the subsurface may take years to impact ground water resources, because liquids and gas often move slowly in the subsurface (see Chapter 6). Additionally, effects may be detected near the activity or at some distance away. For instance, we considered that, depending on the constituents of treated hydraulic fracturing wastewater discharged to a stream and the flow in that stream, drinking water resource quality could be affected a significant distance downstream (see Chapter 8).

This assessment focuses predominantly on activities supporting a single well or multiple wells on a single well pad, accompanied by a more limited discussion of cumulative activities and the effects that could result from having many wells on a landscape. Studies of cumulative effects are generally lacking, but we use the scientific literature to address this topic where possible.[1]

We address *mechanisms* for impacts as well as *impacts* of hydraulic fracturing for oil and gas on drinking water resources. In general, a mechanism is the means or series of events that links an activity to an impact, while an impact is the end result of a mechanism and represents a change in the entity of interest. Specific definitions used in this assessment are provided below.

[1] Cumulative effects refer to combined changes in the environment that can take place as a result of multiple activities over time and/or space.

- A **mechanism** is a means or series of events by which an activity within the hydraulic fracturing water cycle has been observed to change the quality or quantity of drinking water resources.
- A **suspected mechanism** is a means or series of events by which hydraulic fracturing activities could logically have resulted in an observed change in the quality or quantity of drinking water resources. Available evidence may or may not be sufficient to determine if it is the *only* mechanism that caused the observed change.
- A **potential mechanism** is a means or series of events by which hydraulic fracturing activities could logically or theoretically (for instance, based on modeling) change the quality or quantity of drinking water resources but one that has not yet been observed.
- An **impact** is any observed change in the quality or quantity of drinking water resources, regardless of severity, that results from a mechanism.
- A **potential impact** is any change in the quality or quantity of drinking water resources that could logically occur as the result of a mechanism or potential mechanism but has not yet been observed.

Potential mechanisms and impacts, as well as suspected mechanisms, are addressed because data required to document mechanisms and impacts may be inaccessible, incomplete, or nonexistent. In addition, evidence may be insufficient to isolate the contribution of hydraulic fracturing to changes in the quality or quantity of drinking water resources from other human activities occurring nearby. We anticipate that our understanding of mechanisms and impacts will be advanced as the scientific community continues to evaluate potential health and environmental effects of hydraulic fracturing.

In this assessment, we also identify and discuss factors affecting the frequency or severity of changes to avoid a simple inventory of all specific situations in which hydraulic fracturing might alter drinking water quality or quantity. This allows knowledge about the conditions under which effects are likely or unlikely to occur to be applied to new circumstances (e.g., a new area of oil or gas development where hydraulic fracturing is expected to be used) and could inform the development of strategies to prevent impacts. Although no attempt has been made in this assessment to identify or evaluate comprehensive best practices for states, tribes, or the industry, we describe ways to avoid or reduce the impacts of hydraulic fracturing activities as they have been reported in the scientific literature. A summary and evaluation of current or proposed regulations and policies is beyond the scope of this report.

For this assessment, we did not conduct site-specific predictive modeling to quantitatively estimate environmental concentrations of contaminants in drinking water resources, although modeling studies conducted by others are described. Further, this report is not a human health risk assessment. It does not identify populations that are exposed to chemicals or other stressors in the environment, estimate the extent of exposure, or estimate the incidence of human health impacts (see Chapter 9).

This assessment focuses on the potential impacts from activities in the hydraulic fracturing water cycle on drinking water resources. It does not address all concerns that have been raised about hydraulic fracturing nor about oil and gas exploration and production more generally. Activities that are not considered include acquisition and transport of constituents of hydraulic fracturing fluids besides water (e.g., sand mining and chemical production); site selection and well pad development; other infrastructure development (e.g., roads, pipelines, compressor stations); site reclamation; and well closure. We consider these activities to be outside the scope of the hydraulic fracturing water cycle and, therefore, their impacts are not addressed in this assessment. Additionally, this report does not discuss the potential impacts of hydraulic fracturing on other water uses (e.g., agriculture or industry), other aspects of the environment (e.g., air quality or ecosystems), worker health or safety, or communities.

1.3. Approach

This assessment relies on scientific literature and data that address topics within the scope of the hydraulic fracturing water cycle. Scientific journal articles and peer-reviewed EPA reports that have been published containing results from the EPA's hydraulic fracturing study comprise one set of applicable literature. Other literature evaluated includes articles published in science and engineering journals, federal and state government reports, non-governmental organization (NGO) reports, and oil and gas industry publications. Data sources examined include federal- and state-collected data sets, databases curated by federal and state government agencies, other publicly available data and information, and data including confidential and non-confidential business information submitted by industry to the EPA.[1]

1.3.1. EPA Hydraulic Fracturing Study Publications

The research topic areas and projects described in the Study Plan were developed with substantial expert and public input, and they were designed to meet the data and information needs of this assessment. As such, published, peer-reviewed results of the research conducted under the Study Plan are incorporated and cited frequently throughout this assessment. As is customary in assessments that synthesize a large body of literature and data, the results of EPA research are contextualized and interpreted in combination with the other literature and data described in Section 1.3.2. The articles and EPA reports themselves that give complete and detailed project results can be found on the EPA's hydraulic fracturing website (www.epa.gov/hfstudy). For ease of reference, a description of the individual projects, the type of research activity they represent (i.e., analysis of existing data, scenario evaluation, laboratory study, or case study), and the corresponding citations of published articles and EPA reports that are referenced in this assessment can be found in Appendix H.

1.3.2. Literature and Data Search Strategy

The EPA used a broad search strategy to identify approximately 3,700 sources of scientific information that could be applicable to this assessment. This search strategy included both

[1] Information was provided to the EPA by nine hydraulic fracturing service companies in response to a September 2010 information request and by nine oil and gas well operators in response to an August 2011 information request.

requesting input from scientists, stakeholders, and the public about relevant data and information, and thorough searching of published information and applicable data.[1]

Over 1,400 articles, reports, data, and other sources of information were obtained through outreach to the public, stakeholders, and scientific experts. The EPA requested material through many venues, as follows. We received recommended literature from the Science Advisory Board (SAB), the EPA's independent federal scientific advisory committee, from its review of the EPA's draft Study Plan; its consultation on the EPA's Progress Report (U.S. EPA, 2012f); and during an SAB briefing on new and emerging information related to hydraulic fracturing in fall 2013. Subject matter experts and stakeholders also recommended literature through a series of technical workshops and roundtables organized by the EPA between 2011 and 2013. In addition, the public submitted material to the SAB during the SAB review of the draft Study Plan, Progress Report, and briefing on emerging information, as well as in response to a formal request for data and information posted in the *Federal Register* (EPA-HQ-ORD-2010-0674) in November 2012. The submission deadline was extended from April to November 2013 to provide the public with additional opportunity to provide input to the EPA.

Approximately 2,300 additional sources were identified by conducting searches for material that could be applicable to the assessment via online scientific databases and federal, state, and stakeholder websites. We searched these databases and websites in particular for (1) materials addressing topics not covered by the documents submitted by experts, stakeholders, and the public as noted above, and (2) newly emerging scientific studies. Multiple targeted and iterative searches on topics determined to be within the scope of the assessment were conducted until fall 2014. After that time, we largely included newer literature as it was recommended to us during our internal technical reviews or as it came to our attention and was determined to be important for filling a gap in information. In many cases, our searches uncovered the same material submitted by the public, but approximately 2,300 new sources were also identified.

1.3.3. Literature and Data Evaluation Strategy

We evaluated the literature and data identified in the search strategy above using the five assessment factors outlined by the EPA Science Policy Council in *A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (U.S. EPA, 2003). The factors are (1) applicability and utility, (2) evaluation and review, (3) soundness, (4) clarity and completeness, and (5) uncertainty and variability. Table 1-2 lists these factors along with the specific criteria for each that were developed for this assessment. We first evaluated all materials for applicability. If "applicable" under the criteria, the reference was evaluated on the basis of the other four factors.

Our objective was to consider and then cite literature in the assessment that fully conforms to all criteria defining each assessment factor. However, the preponderance of literature on some topics did not fully conform to some aspects of the outlined criteria. For instance, there were many white

[1] This study did not review information contained in state and federal enforcement actions concerning alleged contamination of drinking water resources.

papers and reports in technical areas in which independent peer review is not standard practice or is not well documented. Therefore, we included references in the assessment that were not peer-reviewed but that addressed topics not found in the peer-reviewed literature, that provided useful background information, or that corroborated conclusions in the peer-reviewed literature.

Table 1-2. Criteria developed for the five factors used to evaluate literature and data cited in this assessment.

Criteria are consistent with those outlined by the EPA's Science Policy Council (U.S. EPA, 2003). Criteria are incorporated into the Quality Assurance Project Plans for this assessment (U.S. EPA, 2014g, 2013d).

Factor	Criteria
Applicability	Document provides information useful for assessing the potential pathways for hydraulic fracturing activities to change the quality or quantity of drinking water resources, identifies factors that affect the frequency and severity of impacts, or suggests ways that potential impacts may be avoided or reduced.
Review	Document has been peer-reviewed.
Soundness	Document relies on sound scientific theory and approaches, and conclusions are consistent with data presented.
Clarity/completeness	Document provides underlying data, assumptions, procedures, and model parameters, as applicable, as well as information about sponsorship and author affiliations.
Uncertainty/variability	Document identifies uncertainties, variability, sources of error, and/or bias and properly reflects them in any conclusions drawn.

1.3.4. Quality Assurance and Peer Review

The use of quality assurance (QA) and peer review helps ensure that the EPA conducts high-quality science that can be used to inform policymakers, industry, and the public. QA activities performed by the EPA ensure that the agency's environmental data are of sufficient quantity and quality to support the data's intended use. The EPA prepared a programmatic Quality Management Plan (U.S. EPA, 2014h) for all of the research conducted under the EPA's Study Plan, including the review and synthesis of the scientific literature in this assessment. The hydraulic fracturing Quality Management Plan describes the QA program's organizational structure; defines and assigns QA and quality control (QC) responsibilities; and describes the processes and procedures used to plan, implement, and assess the effectiveness of the quality system. The broad plan is then supported by more detailed QA Project Plans (QAPPs). For instance, the QAPPs developed for this assessment provide the technical approach and associated QA/QC procedures for our data and literature search and evaluation strategies introduced in Section 1.3.2 and 1.3.3 (U.S. EPA, 2014g, 2013d). A QA audit was conducted by the QA Manager during the preparation of this assessment in order to verify that the appropriate QA procedures, criteria, reviews, and data verification were adequately performed and documented. Identifying uncertainties is another aspect of QA; uncertainty, including data gaps and data limitations, is discussed throughout this assessment.

This report is classified as a Highly Influential Scientific Assessment (HISA), defined by the Office of Management and Budget (OMB) as a scientific assessment that (1) could have a potential impact of more than $500 million in any year or (2) is novel, controversial, or precedent-setting or has significant interagency interest (OMB, 2004). The OMB describes specific peer review requirements for HISAs. The EPA often engages the SAB as an external federal advisory committee to conduct peer reviews of high-profile scientific matters relevant to the agency. Members of an ad hoc panel, the same panel that was convened under the auspices of the SAB to provide comment on the Progress Report, will also provide comment on this assessment.[1] Panel members were nominated by the public and chosen to create a balanced review panel based on factors such as technical expertise, knowledge, experience, and absence of any real or perceived conflicts of interest.

1.4. Organization

This assessment begins with a general description of hydraulic fracturing activities and the role of hydraulic fracturing in the oil and gas industry in the United States (see Chapter 2). It follows with a characterization of drinking water resources in the continental United States, with a focus on areas in which we estimate hydraulic fracturing has taken place over the time period of 2000–2013 (see Chapter 3).

Chapters 4 through 8 are organized around the stages of the hydraulic fracturing water cycle (see Figure 1-1) and address the potential for activities conducted during those stages to change the quality or quantity of drinking water resources. Each of the stages is covered by a separate chapter. There is also a chapter devoted to an examination of the properties of chemicals and constituents that have been or may be used in hydraulic fracturing fluids or present in flowback and produced water (see Chapter 9).

Each chapter addresses research questions developed under the Study Plan, as data and information allow (see Table 1-3). Concise answers appear in text boxes at the end of each chapter. The final chapter provides major conclusions and a synthesis of information presented across the assessment. It also highlights significant gaps in information that contribute to uncertainties about those conclusions (see Chapter 10).

Table 1-3. Research questions addressed by this assessment.

Each chapter addresses research questions developed under the Study Plan. Chapters 2 and 3 develop background on hydraulic fracturing and drinking water resources, respectively.

Chapter and water cycle stage	Research questions

[1] Information about this process is available online at http://yosemite.epa.gov/sab/sabproduct.nsf/02ad90b136fc21ef85256eba00436459/b436304ba804e3f885257a5b00521b3b!OpenDocument.

Chapter and water cycle stage	Research questions
Chapter 4 - Water Acquisition	• What are the types of water used for hydraulic fracturing? • How much water is used per well? • How might cumulative water withdrawals for hydraulic fracturing affect drinking water quantity? • What are the possible impacts of water withdrawals for hydraulic fracturing on water quality?
Chapter 5 - Chemical Mixing	• What is currently known about the frequency, severity, and causes of spills of hydraulic fracturing fluids and chemical additives? • What are the identities and volumes of chemicals used in hydraulic fracturing fluids, and how might this composition vary at a given site and across the country? • What are the chemical and physical properties of hydraulic fracturing chemical additives? • If spills occur, how might hydraulic fracturing chemical additives contaminate drinking water resources?
Chapter 6 - Well Injection	• How effective are current well construction practices at containing fluids- both liquids and gases- before, during, and after fracturing? • Can subsurface migration of fluids- both liquids and gases- to drinking water resources occur, and what local geologic or artificial features might allow this?
Chapter 7 - Flowback and Produced Water	• What is currently known about the frequency, severity, and causes of spills of flowback and produced water? • What is the composition of hydraulic fracturing flowback and produced water, and what factors might influence this composition? • What are the chemical and physical properties of hydraulic fracturing flowback and produced water constituents? • If spills occur, how might hydraulic fracturing flowback and produced water contaminate drinking water resources?

Chapter and water cycle stage	Research questions
Chapter 8 - Wastewater Treatment and Waste Disposal	• What are the common treatment and disposal methods for hydraulic fracturing wastewater, and where are these methods practiced? • How effective are conventional publicly owned treatment works and commercial treatment systems in removing organic and inorganic contaminants of concern in hydraulic fracturing wastewater? • What are the potential impacts from surface water disposal of treated hydraulic fracturing wastewater on drinking water treatment facilities?
Chapter 9 - Hazard Evaluation of Chemicals Across the Water Cycle Stages	• What are the toxicological properties of hydraulic fracturing chemical additives? • What are the toxicological properties of hydraulic fracturing flowback and produced water constituents?

1.5. Intended Use

We expect that this report, as a synthesis of the science, will contribute to the understanding of the potential impacts of hydraulic fracturing on drinking water resources and the factors that may influence those impacts. The data and findings in this report can be used by federal, tribal, state, and local officials; industry; and the public to better understand and address any vulnerabilities of drinking water resources to hydraulic fracturing activities.

We expect this report will be used to help facilitate and inform dialogue among interested stakeholders, including Congress, other federal agencies, states, tribal governments, the international community, industry, NGOs, academia, and the general public. Additionally, the identification of knowledge gaps will promote greater attention to these areas by researchers.

We also expect this report may support future assessment efforts. For instance, we anticipate that it could contribute context to site-specific exposure or risk assessments of hydraulic fracturing, to regional public health assessments, or to assessments of cumulative impacts of hydraulic fracturing on drinking water resources over time or over defined geographic areas of interest.

Finally, and most importantly, this assessment advances the scientific basis for decisions by federal, state, tribal, and local officials; industry; and the public on how best to protect drinking water resources now and in the future.

1.6. References for Chapter 1

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